GEOGRAFICKÝ ČASOPIS

56 2004 3

Blaž Komac, Matej Gabrovec**

SOME CHARACTERISTICS OF DOLOMITE RELIEF IN SLOVENIA

B. Komac, M. Gabrovec: Some characteristics of dolomite relief in Slovenia. Geograficky časopis, 56, 2004, 3, 4 figs., 32 refs.

The paper discusses geomorphological features of Slovenia's dolomite areas, which cover about a tenth of its surface. It describes the most important dolomite relief features in Slovenia and analyses the most important geomorphological processes. Dolomite is a carbonate rock so it is easily dissolvable in water. Compared with limestone relief, the transformation process in dolomite relief is more rapid due to the high rate of physical weathering processes. Geomorphological fieldwork was carried out in two case areas in the Polhov Gradec hills and on the Žibrše plateau. Characteristic relief has developed in dolomite areas due to the interaction of fluvial and karst processes, which have so far (sometimes incorrectly) been designated as fluvial karst.

Key words: geomorphology, dolomite relief, denudation, Slovenia

INTRODUCTION

In Slovenia, dolomite covers 2,500 km^2 of surface area or 11.7 % of the national territory. We distinguish twelve types of dolomite, the most frequent being Mesozoic dolomite, particularly Triassic dolomite. The proportion of dolomite areas in Slovenia is greatest in the Dinaric karst region, where it covers one fifth of the surface, and in the Alpine areas (Perko 2001), where it covers one sixth of the surface (Gabrovec 1994).

*Anton Melik Geographical Institute, Gosposka ulica 13, SI-1000 Ljubljana, Slovenia

IMPORTANT GEOMORPHOLOGICAL PROCESSES IN DOLOMITE AREAS

In current conditions, dolomite is subject to intensive physical and chemical weathering. Due to its porosity, stratification, and fracturedness and because of its initial disintegration into rubble or sand, it is particularly subject to weathering. Dolomite rubble is being formed today in Slovenia at higher elevations, but it formed in larger quantities during the colder periods of the Pleistocene. Dells, for example, are a legacy of the periglacial conditions that dominated in the hilly areas of western and central Slovenia during the Pleistocene. Although weathering did not extend to the greater depths, denudation has removed weathered debris and revealed their structural composition. Characteristic solifluction slopes and fans were formed, where we can today observe dolomite and limestone rubble covered with soil (Habič 1968, Šifrer 1990). In current conditions, intensive chemical weathering is occurring on dolomite.

A comparison of measurements of water hardness and the volume of flow of the Predvratnica stream near Velike Lašče in three different places showed that the annual corrosion between its sink in the Vratnica Cave and its 1,150-meters distant source in Peči totals as much as 74 tons of $CaCO_3$ (Kogovšek and Kranjc 1992). Although the waters from dolomite regions are saturated or even supersaturated with dolomite, the dolomite is not deposited due to the slow kinetics or greater mobility in comparison with calcite (Lapanje 2000).

Fig. 1. Typical dell relief on the Žibrše plateau

In dolomite areas without vegetation in the mountain and high-mountain world, denudation plays an important role (Kunaver 1990). Steep slopes composed of fractured rock are particularly erodible, and erosion gullies appear. Wind and snow erosion on dolomite areas do not play an important geomorphological role in present conditions.

PRINCIPAL RELIEF FORMS ON DOLOMITE

The majority of dolomite in Slovenia was formed by the dolomitization of limestone. Transitions between the two rocks are frequent and are reflected in the formation of the surface. Dolomite surfaces can be karstic, but are frequently crisscrossed by elements characteristic of fluviodenudational surfaces. Although karstic and fluviodenudational processes take place simultaneously, they are competing processes.

Tectonics, which breaks and crumbles the rock, has an important influence on the morphology. Karst relief forms where the dolomite is only fissured; however, if the rock is fractured, fluvial relief is formed because of its poorer permeability. Morphologically, geomorphological systems overlap, but the transitions are not of genetic character. For this reason we cannot speak of fluviokarst (Roglić 1957 and 1960) as a special type of relief, but only of karst dolomite relief transformed by fluviodenudational processes (i.e., fluvial-karst relief) or about fluviodenudational relief with elements of karst relief (i.e., karst-fluvial relief).

Below, we offer a short survey of the most characteristic relief forms on dolomite areas in Slovenia.

On dolomite, erosion foci appear at higher elevations where the surface is not covered by vegetation, on steeply inclined slopes, and on fractured rock. These are original areas of intensive slope processes of greater extent. On denuded dolomite ground, precipitation and water erosion cause the occurrence of erosion channels and gullies, which contribute greatly to the erosion of the slopes. In western Slovenia, the lower parts of Alpine valleys are cut into dolomite, while in the Karavanke Mountains there are many valleys that run from north to south crossing belts of dolomite. In these areas, high vertical dolomite walls are rare; more frequent are steep slopes with numerous ravines and gullies.

A dell, sometimes also called *dry valley* in English or *die Delle* in German, is a “long and narrow half-cylindrical valley where no traces of linear erosion are visible”. In Slovenia it is a characteristic form on dolomite relief although it may also form on other types of rock, such as granite, clay and loess (Pécsi 1964, p. 40).

The upper part of a dell starts with a shallow bend and widens and deepens downwards. It reaches several hundred meters in length and several dozen meters in depth at most. At the top, it has no permanent water stream, but farther down it can transform into a ravine with permanent water stream. On rare occasion, it is left hanging over a steep slope or ends in a plain or a sinkhole. In cross-section, it has a concave bottom that continues to relatively steep slopes. The bottom can be level due to farming, in which case it changes into steep slopes at a distinctive edge.

Dells are usually linked in a branched system, which reflects the fact they were formed by the actions of creeping, solifluction, and periodic surface-running water. They are supposed to be the legacy of colder periods and were formed due to intensive weathering and denudation on areas of weaker or fractured rock. Today, their deepening occurs due to the more intensive corrosion on the bottom, which is the consequence of a thicker layer of soil and weathered debris. This is also influenced by the characteristics of the relief (the length of slopes) and the lithological and tectonic composition and structure. The fractured nature of dolomite along overlaps and faults reduces its permeability and resistance, which enables the formation of dells beside them through denudation processes. Relief details are influenced by the lithological composition, as well as by the geological structure.

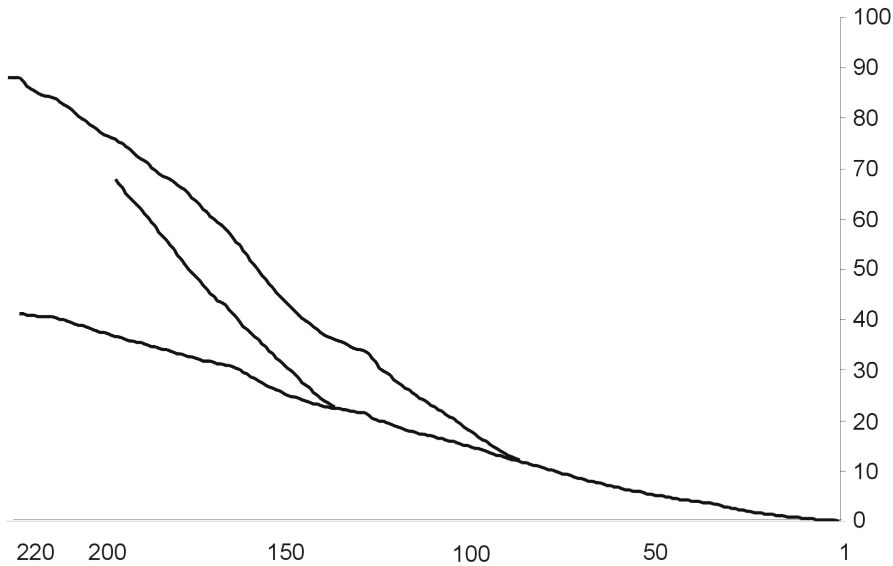

Fig. 2. A cross-section of three dells on Žibrše dolomite relief. The measurements were made by 1,5 m long pantometers (scale is in meters)

The occurrence of saddles is also linked to the direction of joints and the more rapid lowering of the surface due to the locally less resistant rock.

Dell surfaces often change into hummocky surfaces. Dolomite hummocks occur due to variations in the resistance of the rock. They are of various shapes and sizes, usually from a few meters to several dozen meters long and from a few decimeters to several dozen meters high. Hummocks develop through the irregular disintegration of rock due to frost weathering and the surface washing of weathered material to lower areas. For this reason they are found more frequently in relatively higher locations. To a large degree, they formed in periglacial conditions, but today their continued differentiation occurs through corrosion. These forms are found particularly on the high Dinaric plateaus of western Slovenia and in the Dinaric valley systems of eastern Slovenia (Habič 1968).

Due to locally higher resistance of dolomite, pinnacles are formed by frost weathering, surface washing, and subcutaneous karstification. The surrounding surface lowers faster than the resistant areas, which remain at the higher elevation. Pinnacles are pyramid-shaped or conical forms, also rounded on top, pointed, or finger-like. They are rarely overhanging. On dolomite, they formed along joint zones or on vertically set rock layers. In Slovenia, they occur frequently in the Julian Alps and the Kamniške-Savinjske Alps, the Posavsko and Kozjansko hills, the Polhov Gradec hills, the Idrijsko-Cerkljansko hills, and the high Dinaric plateaus of western Slovenia (Hrovat 1953, Puc 1984).

Dolines on dolomite are quite frequent in less dolomitized and fissured dolomites. They are linked to crushed-collapsed or fissured zones of faults and the lithological contact of dolomite with limestone (Čar 2001, Čar and Šebela 2001). They vary in shape, size, depth, and diameter. Bowl-like shapes dominate, and there are fewer basin-like shapes with steep and gentle slopes. They are frequently shallower and less distinct than dolines on limestone because physical weathering and the washing away of dolomite gravel obstruct the karst dissection of the surface.

Dolomite is found in the bedrock of the majority of the karst poljes in the Dinaric karst region (Rus 1924, Gams 2003) and is undoubtedly important in their morphological and hydrogeographical development. However, we cannot conclude that it also plays the decisive role in their formation. The poljes of the Logatec, Cerknica, Lož, Radenci, Črni vrh, Zadlog, Dobrepolje, Ribnica, and Kočevje areas lie on similar lithological contacts. The floor of the Planina polje is composed entirely of dolomite. The occurrence of poljes along fault contacts between limestone and dolomite is also possibly linked with the fact that the fault zones on the dolomite side are wider. Dolomite is less plastic than limestone and breaks during shifts. Because the entire dolomite area compensates for the deformation, it is more heavily transformed and for this reason some karst poljes are wider on the dolomite side. Such fault contacts are often a few hundred meters wide and practically impermeable for water. Therefore the development of contact areas between limestone and dolomite is also connected with the weaker resistance of dolomite to physical weathering and denudation or to the greater permeability of limestone. For this reason, geomorphological development is closely related to climatic conditions. The bottoms of karst poljes are largely covered by weathered debris and are therefore only affected by chemical weathering today (Roglić 1957).

ŽIBRŠE PLATEAU – A DOLOMITE SURFACE

The Žibrše plateau is located in the southern part of the Rovte hills. The area belongs to the Idrija-Žiri overlap structure, which is characterized by many extensive overlaps or nappes. On the Žibrše plateau, stratified main dolomite appears with brown or grey dolomite marl in its lower part contains (Mlakar 1969).

The Upper Triassic dolomite has been shaped into polyhedrons and is fractured along the faults. The fractured rock is covered with a more or less thick layer of weathered debris or rubble. We attempted to determine dip and orientation of the fractures, degree of fracturing of the rock and the dip of the rock layers from the direction of the fissures in nearby outcroppings, which run roughly parallel with the direction of the faults.

Faults of the southeast-northwest Dinaric orientation, which are usually longer and stronger than the transverse faults, dominate. The rock layers of the Žibrše plateau run toward the southwest with inclinations from 20° to 40°. Several dells, ravines, saddles, ridges, dolines, and convex slopes on dolomite on the Žibrše plateau originated on fault zones or alongside them.

A spring formed near the contact between the upper dolomite and the lower dolomite of less permeable marl layers. The position of the spring is interesting since it occurred at the juncture of three dells, and the less permeable joints running alongside the dells also contributed to the location of the spring. Karst dolomite regions are clearly significant catchment areas. As we also noted the hydrogeographical characteristics of dolomite depend particularly on the degree of fracturing, the position of dolomite relative to other lithological elements, the production of rubble, and the relief (Lapanje 2000, Zogović 1966).

With the help of a digital relief model employing 5×5-meter cells, we calculated the area of the bottoms of the dells (2.45 hectares) and the orographical surroundings of the springs (23.52 hectares). In this area, the annual precipitation amounts to about 1,800 mm, evapotranspiration totals about 600 mm (Kolbezen and Pristov 1998), and the specific outflow is 38 $l/s/km^2$. Habič's (1968) calculations for the nearby Hotenjka River give a figure of 50 $l/s/km^2$. According to Habič (1970), the usual outflow coefficient on dolomite is 0.5, while on the Žibrše plateau it is 0.7, which is linked to the inclination of the surface and its northern facing location.

The average volume of flow of the spring (about 0.2 l/s), considering the specific outflow, indicates that water flows to the spring from an area of about 0.5 hectares. This is a five times smaller area than the area of the bottom of the dells around the spring. The amount of the underground outflow is barely a fortieth of the total outflow from the hypsographically limited area around the spring (9 l/s). Field observations showed that after heavy precipitation, the water runs off quickly on the surface or just under it, as Habič states (1968). However, we did not trace the occurrence of groundwater flows. Magnesium and total hardness are very high due to the completely dolomite surroundings and the unbroken soil blanket. The magnesium hardness (129.1 mg/l) encompasses as much as 51 % of the total hardness (251.9 mg/l), while the carbonate hardness is 221.6 mg/l.

Given the value of the specific outflow, which is 40 $l/s/km^2$, and the hardness of the water, we can calculate the speed of the corrosion lowering of the surface, which on the Žibrše plateau totals 121 $m^3/km^2/a$ (m/ka). For the Hotenjka catchment area, Habič (1968, 216) states a value of 126 m^3/km^2/year.

On dolomite areas, red-brown clay frequently covers the surface in an unbroken layer or lies at the bottom of hollows and pockets. In the Dolenjska valley system, for example, it stretches from Šmarje-Sap to Trebnje in a flat, half-meter to ten-meter deep and five- to ten-kilometer wide belt. It has not been found further north. Some speculate that part of this sediment was brought to this area from the Posavje hills (Habič 1988) and covered the primary red clays, while others speculate that it is Pleistocene sediment, the insoluble remains of the dissolving bedrock (Gregorič 1964, Buser 1974). The older the soil, the fewer carbonate elements are in it; it is therefore more acidic and its properties do not depend so much on the properties of dolomite. For red-brown soil to occur, a very large amount of rock must have been dissolved. We also found red-brown clay under shallow brown soil at individual sites on the Žibrše plateau. We found the largest site in an approximately three-meter deep hollow in the shallow upper part of a dell. The surrounding surface transforms into an undulating or stair-like relief.

The clay was brought to its current site from higher elevations where it no longer exists today. We conclude that it originally covered a larger part of the surface because there are individual clay areas in smaller depressions in very diverse locations, for example, in hollows on top of ridges and especially at the bottom of dells where the clay lies beneath a layer of dolomite rubble later transported to the dells. Brown soil formed on the surface in the recent period. Between the rock and the clay is an up to 0.5-meter thick clayey transitional belt with chunks of weathered rock with a powdery surface. Here, individual minerals have leached from the rock, while others remain in it. Its crystal structure becomes porous and less stable (see Zupan Hajna 2002). On the surface of the rock particles and in their surrounding, a dust-like coating of corroded rock particles accumulates, which can be removed by rubbing with the fingers and which extends up to 1.5 mm deep in the rock. Weathering is also proven by the corrosion dissected subcutaneous surface.

In the hollow mentioned, there was a three-meter thick layer of clay or about 16,000 m^3. Dolomite contains only a small percentage of insoluble material at most. If the rock is homogenous, about 100 m^3 of the rock must dissolve for 2.5 m^3 of clay to occur (Gregorič 1964). If the clay occurred in the area of a hollow with 500 m^2, almost 640,000 m^3 of rock would have to dissolve to produce such a quantity of clay, which would take a million years with the equivalent of dissolving the rock at 0.12 mm/a. Buser (1974) cites paleontological evidence that such sediment in Dolenjska is of Pleistocene age. The clay was probably formed at least partially *in situ*. The weathering front between the clay and the bedrock indicates the penetration of water along the fissures and small channels formed through the activities of plants and animals. Some observations indicate the poor permeability of the clay, which is also one of the causes of flooding.

We measured the depth of the soil or weathered debris in six cross-sections. In the middle of dells where material is not washed away by the water flowing in from the slopes, we encounter larger or smaller quantities of clay. The depth of the clay depends on the thickness of the soil and debris accumulation and the morphology of the rock base. There is more clay in the middle part of the dell bottoms and less at the junction with the slopes, probably the consequence of the erosion activity of surface water flowing down from the slopes. The bottoms are slightly convex in cross-section. In places, the clay is ten centimetres deep, but usually we encounter clay between forty and fifty centimetres deep. Along the sides of the dells, the clay layer ends in a wedge shape, and under the shallow soil is dolomite rubble only. The weathered debris on the bottom of dells at higher sites is shallower than in dells in lower locations. Where the dells are narrower (4 m), there is less clay due to erosion. Denudation plays the largest role on inclined areas of fractured rock alongside faults. In dell bottoms, moisture accumulates in clay, which enables corrosion. We can judge the thickness of the clay by the vegetation. In contrast, the brown soil that covers slopes has a low retention capability. On steep slopes, it is overgrown with forest, while on flat surfaces it is good agricultural soil. In dolomite karst regions, land use and settlement is bound to such areas, which is why there are more meadows, and to some extent cultivated fields in dolomite areas in Slovenia in comparison with limestone areas. There is also less forest on dolomite than on other carbonate rocks (Gabrovec 1995c, Roglić 1958).

It appears today that corrosion is most intensive on the bottoms of dells where the soil or weathered debris is thicker than on steep slopes where the water runs off quickly. Corrosion is also more intensive on less dolomitized areas. In such places, the dolomite is usually fissured and dolines are frequent. On the Žibrše plateau, dolines formed in the northwestern part of the plateau near the tops of slopes. On dolomite, ravines and gullies form in fractured or crushed zones, and lateral valleys form between elevations and ridges. Karstification and the types of karst phenomena are also influenced by the dissection or morphology of the surface (Zogović 1966).

Dells on the Žibrše plateau are usually concave in cross-section, while those shaped by cultivation have a flat bottom, which meets the sloping sides at a sharp angle. On the Žibrše plateau, they end at the upper edge of slopes at an altitude of 600 meters. There are springs on the upper edge of the plateau so we assume it formed due to locally less resistant rocks. The dells are interconnected in an asymmetric treelike system, but no permanent surface waters flow along their bottoms today. They also run along faults or fractured zones where rock particles are quickly washed away. Larger basins and saddles appeared at the intersections of faults. The formation of the dells parallel to the Idrija fault is mainly tectonically conditioned; the others are oriented relative to the stratification structure and follow less resistant few-decimeter to several-meter thick layers of marl, schistose marl, and schistose claystone. Where these rocks are exposed on the surface, weathering is more intensive and removal stronger than in the surrounding areas and thus an undulating relief is created.

The dells were most probably formed by weathering and periglacial processes in the Pleistocene such as nivation and solifluction. At that time, water flowed across the bottom of the dells only during the thawing of snow and ice. In today's conditions, there is no trace of erosion by surface water flow in dells. In dells covered with turf, unconcentrated flows of water, which carry away soil, appear during intense precipitation. Denudation depends primarily on the weathering of the rock, the inclination of the surface, the thickness of the soil or weathered debris, and the vegetation.

Where geomorphological processes were not active long enough or were not intensive enough for dells to occur, hummocky and stepped or undulating surfaces can be observed. Smaller hummocks follow the stratification or the lithographical structure, and larger hummocks follow fault structures. Where some of the dells in their upper part end almost imperceptibly in a hummocky surface, the outline of the future development of the surface can be foreseen. Some such dells were left hanging, and their lower parts proceed to the next dell with pronounced several-meter step. During the period of observation, as much as

26.3 kilograms of material accumulated at the measuring site, which totals about 25 g/m^2 in a single storm. Annual denudation totalled 12 t/ha, too low a figure given the other observations. This is most probably the consequence of the too small size (1.5 m^2) of the measuring site (Komac 2003).

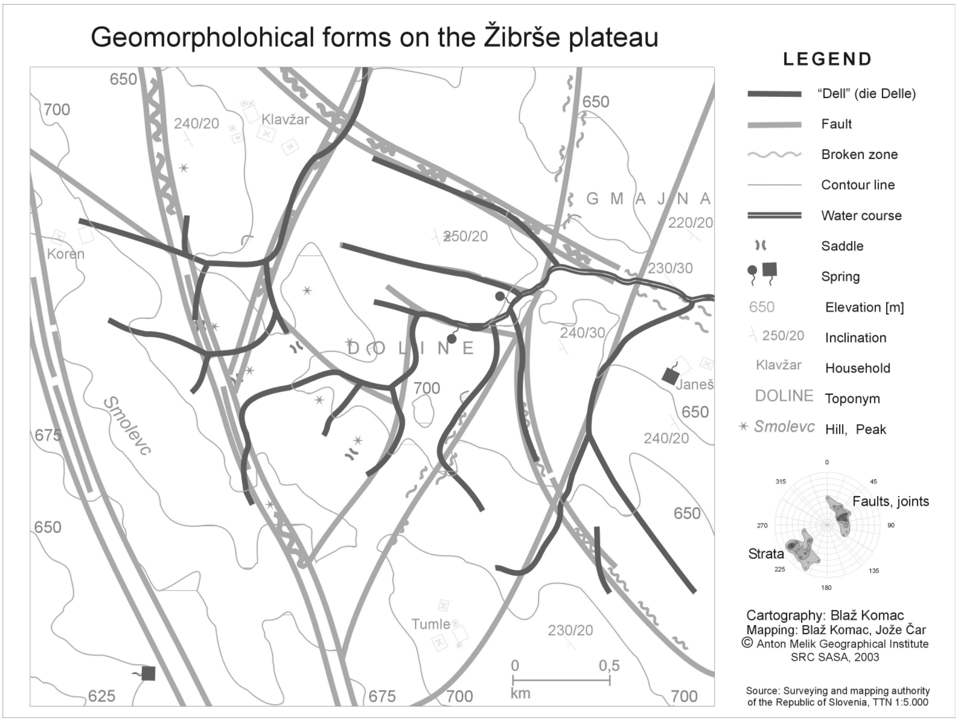

Fig. 3. A map showing the dependence of relief forms on the tectonic structure

POLHOV GRADEC HILLS

The Polhov gradec hills occupy around 300 km^2 in Slovenia's subalpine world between the Rovte hills and the valley of the Sava River and its tributary the Sora.

The fieldwork took place in the Jevc ravine above the Mala Božna valley in the Gradaščica River catchment area. Above the ravine a high ridge rises to 885 m (Mt. Špikelj), a west spur of the higher range in the central part of the Polhov gradec hills, which has Mount Tošč (1,021 m) as its highest peak.

Due to the overlapping of the more resistant and younger dolomite layer over the less resistant Permian flint sandstone (Rakovec 1939), the Middle Triassic dolomite is heavily fractured. In it, a steep relief formed with numerous erosion gullies, most of which end before they reach the rock contact. Along this contact, many weak but permanent springs developed. The faults run in a northeast-southwest direction while the rock layers incline at 50° toward the west.

The area is subject to intensive geomorphological processes, in particular surface washing and erosion as the consequence of the tectonic structure, the proximity of the depression of the Ljubljana Basin, and the fracturedness of the rock.

By measuring the material carried away between October 12, 2001, and October 15, 2002, we measured the level of erosion at the bottom and on the slopes of the 130-meter long and 5- to 10-meter wide erosion gully with an area of 750 m^2. In a small erosion gully we used dolomite sand and gravel to create an approximately forty-centimetre wide shelf (site coordinates: 46° 5' 45'' and 14° 18' 2''). We levelled and modified its surface so that water would flow off slowly. We could thus collect the material released from the slope above it and prevent it being washed away. Larger pieces of rock that rolled down the slope also stopped on the shelf. Above the artificial shelf was a twelve-meter long steep slope (42°) composed of fractured rock, varying in width from 4.5 meters in the upper part to 5.5 meters in the widest part and two meters at the bottom. The surface above the measuring field amounted to 45 m^2 or approximately 6 % of the surface area of the erosion gully. We cleared the measuring field regularly, saving the material in plastic bags and weighing it. From the quantity of material collected, we calculated the intensity of the geomorphological processes. We had to renew the measuring field occasionally due to intensive precipitation (for example, on September 5, 2002). In this period, we gathered 55.2 kilograms of material, which annually would amount to as much as 175 t/ha. Compared with the measurements on the Žibrše plateau, this result is more realistic since the measuring field was larger. The result shows exceptionally heavy erosion, which is the consequence of the fracturedness of the rock and the steepness of the slope. Physical weathering of the dolomite and erosion in this area surpass corrosion by a factor of 10 (Komac 2003).

Higher up the ravine, we also dammed the bottom of a 13-meter wide erosion gully where the bedrock was thickly covered with material. An approximately one-meter wide and 0.5-meter high shelf was created, which we covered with polyvinyl and arranged for the periodical outflow of surface water. During the period of observation at this site, we did not record any movement of smaller material since only a few larger pieces of rock that rolled down the scree were stopped by the dam. Compared with the first measuring field, the geomorphological processes were more intensive but also rarer. Material moved only once due to heavy precipitation (September 16, 2002). The movements of the material were the consequence of rockfalls, which are very frequent on carbonate rocks in Slovenia (Zorn 2002) and produce the largest amount of material in the erosion gullies, which is then removed by erosion.

Due to the permeability of the dolomite scree, the water flows under the surface. A surface flow only appears when the material is saturated with water. Subcutaneous streams wash away tinier fragments, while the coarser material remains in place. The measuring field was completely destroyed by heavy erosion following heavy precipitation on August 20, 2002, when 15.6 mm of rain fell in seventy-five minutes (12.48 mm/h). The maximum precipitation recorded during the observation period occurred on August 4, 2002, with an intensity of 13.2 mm/h. On September 5, 2002, the gully deepened by another 0.7 meter, even though there was no especially intensive precipitation in this period. This shows the exceptional intensity of the shifting of the material on the slope, which depends especially on the saturation of the surface and the duration and intensity of precipitation, the triggers of geomorphological processes. In the saturated material, erosion also causes the greater shifting of material.

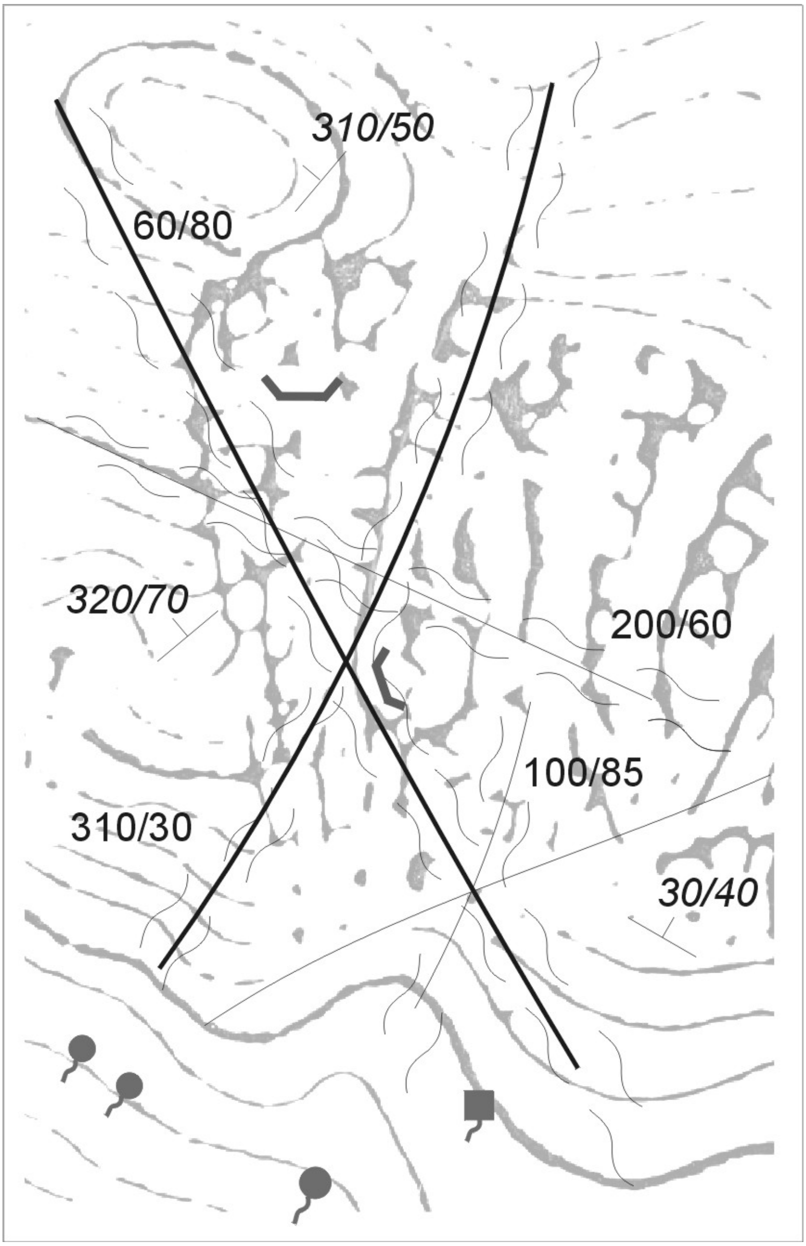

Fig. 4. A map showing the main relief characteristics and dependence of dolomite karst springs on the tectonic structure

The water usually flows through the material; surface water flow is rare. Inside the sediment, there is a branched network of water streams that run from the edges (walls and slopes of the gully) toward the centre of the gully and from the upper part of slopes downwards. Many parallel streams can occur, running in the more permeable layers and uniting further down. With the rising of the groundwater, a uniform level is established that also maintains the level of the underground water in erosion gullies. Due to the varying composition of the sediment, a surface flow appears before the sediment is completely saturated with water.

On the bottom of the erosion gully, there are many springs, which collect water from the area around the erosion gully and water that flows in from the dolomite. The springs occurred at the overlap contact with the impermeable sandstone and are bound to the direction of the rock layers (300/50) and faults (200/60).

Above the erosion gully, a scree formed whose upper part reached the ridge, and the erosion gully carves into it from the bottom up. We attempted to determine the intensity of the geomorphological processes on the scree, and for this purpose we marked straight lines with sprays of various colours on March 8, 2002. During the period of observations, however, it was impossible to quantitatively determine any movements. We also sprayed lines above the upper and the lower observation fields. During a visit on August 9, 2002, we found rocks marked with orange on March 8, 2002, from the upper observation field in the lower part of the erosion gully. They had travelled the distance of about 150 m after the precipitation on August 4, 2002. This event did not trigger any major geomorphological process. After the destruction of the measuring field, we found sprayed rock fragments by the road at the lowest points in the erosion gully. Aridophilous and pioneering species of Scots pine (*Pinus sylvestris L.*), hop hornbeam (*Ostrya carpinifolia Scop.*), and willow (*Salix caprea L.*) dominate on the scree. Older trees are rare because the plants are vulnerable to slope processes. We measured the height and diameter of the trunks of 137 pine trees. The average height (87 cm) and diameter (3.44 cm) indicate poor growing conditions and relative youth of the population.

In spite of intensive geomorphological processes, only a little of the material reaches the valley bottom, something less than the average in Slovenia (40 %, cf. Horvat 1998). This occurs only rarely, for example, with rockslides followed by erosion. Dolomite disintegrates during transportation, and for this reason we do not find larger pieces in lower positions. Particularly important processes include frost weathering, surface washing and erosion, rock flow, and collapses and falls. These are primarily influenced by the dolomitization, stratification, and fracturedness of the rock. On scree, the material in channels is sorted by length and diameter. Slopes are also destabilized by larger movements of material eroding the bottoms of gullies. Rock flow material is more compact and holds moisture for a longer time comparing to scree material.

CONCLUSION

The results of the studies show that relatively intensive geomorphological transformation takes place on dolomite areas. Corrosion, surface washing, and erosion are particularly important processes. The ratio between them or their effects depends primarily on the relief characteristics and the type and fracturedness of the dolomite. In individual areas, corrosion is the more important process, especially in the bottoms of dells and in areas of fractured dolomite, which allow the underground flow of water. Surface washing is the most important process on steep bare and grassy dolomite slopes. Surface washing and erosion depend on tectonic fracturing and the direction of faults. Geomorphological and structural-geological charting indicated that dells, a characteristic relief form on the dolomite of the Žibrše plateau, form along faults. Their direction is also influenced by the lithological structure or the contact between main dolomite and less resistant marl. A characteristic surface evolved on which the linked dells are arranged in the form of a treelike network. The intensity of surface washing and erosion or the carrying away of material on steep dolomite slopes is comparable to these processes on other rock.

REFERENCES

BUSER, S. (1974). *Ribnica, Tolmač osnovne geološke karte SFRJ v merilu 1 : 100 000*. Beograd (Savezni geološki zavod).

ČAR, J. (2001). Structural bases for shaping of dolines. *Acta Carsologica*, 30 (2), 239-256.

ČAR, J., Šebela, S. (2001). Karst characteristics of thrust contact limestone-dolomite near Predjama. *Acta Carsologica*, 30 (2), 141-156.

GABROVEC, M. (1994). *Relief in raba tal na dolomitnih območjih Slovenije*. Doktorska disertacija, Filozofska fakulteta, Oddelek za geografijo, Ljubljana.

GABROVEC, M. (1995). Dolomite areas in Slovenia with particular consideration of relief and land use. *Geografski zbornik*, 35, 7-44.

GABROVEC, M. (1996). Dolinka, dolek ali dolec? *Geografski vestnik*, 68, 261-263.

GAMS, I. (1968). Geomorfološko kartiranje na primeru Rakitne in Glinic, Slovenia. *Geografski vestnik*, 40, 69-88.

GAMS, I. (2003). *Kras*. Ljubljana (Založba ZRC SAZU).

GREGORIČ, V. (1964). *Nastanek tal na triadnih dolomitih*. Doktorska disertacija, Fakulteta za naravoslovje in tehnologijo, Ljubljana.

HABIČ, P. (1968). *Kraško ozemlje med Idrijco in Vipavo*. Dela SAZU, 21. Ljubljana (SAZU).

HABIČ, P. (1970). Presihajoči kraški izvir Lintvern pri Vrhniki. *Acta Carsologica*, 5, 189-203.

HABIČ, P. (1988). Tektonska pogojenost kraškega reliefa zahodne Suhe krajine. *Acta Carsologica*, 17, 35-64.

HORVAT, A. (2001). *Metode določanja erozijsko ogroženih območij*. Doktorska disertacija, Fakulteta za gozdarstvo, Ljubljana.

HROVAT, A. (1953). *Kraška ilovica: njene značilnosti in vpliv na zgradbe*. Ljubljana (Državna založba Slovenije).

KOGOVŠEK, J., KRANJC, A. (1992). Intenzivnost zakrasevanja v dolomitnem krasu. *Geografski vestnik*, 64, 9-18.

KOMAC, B. (2003). *Geomorfne oblike in procesi na dolomitu*. Masters thesis, Filozofska fakulteta, Oddelek za geografijo, Ljubljana.

KUNAVER, J. (1990). H geomorfologiji dolomitnega prevala Vršič v Julijskih Alpah. *Geografski vestnik*, 62, 79-98.

LAPANJE, A. (2000). *Hidrogeologija dolomitnega vodonosnika Mirne gore na severozahodu Bele Krajine*. Masters thesis, Fakulteta za naravoslovje in tehnologijo. Ljubljana.

MLAKAR, I. (1969). Krovna zgradba idrijsko žirovskega ozemlja, *Geologija*, 12, 5-72.
PÉCSI, M. (1964). *Ten years of physicogeographic research in Hungary*. Budapest (Akadémiai Kiadó).
PERKO, D. (2001). *Analiza površja Slovenije s stometrskim digitalnim modelom reliefa*. Ljubljana (Založba ZRC).
PUC, M. (1984). Babe in dedci (Pinnacles). *Proteus*, 47, 167-174.
RAKOVEC, J. (1939). Prispevki k tektoniki in morfogenezi Loških hribov in Polhograjskih dolomitov. *Geografski vestnik*, 15, 99-121.
ROGLIĆ, J. (1957). Zaravni na vapnencima. *Geografski glasnik*, 19, 103-134.
ROGLIĆ, J. (1958). Krš u dolomitima između Konavskog polja in morske obale. *Geografski glasnik*, 20, 129-137.
ROGLIĆ, J. (1960): Das Verhältnis der Fluβerosion zum Karsprozeβ. *Zeitschrift für Geomorphologie,* 4, 116-128.
RUS, J. (1924). Morfogenetske skice z Notranjske strani. *Geografski vestnik*, 1.
ŠIFRER, M. (1983). Kvartarni razvoj Škofjeloškega hribovja. *Geografski zbornik*, 22, 139-195.
ŠIFRER, M. (1990). Razvoj reliefa na Slovenskem v luči klimatske geomorfologije. *Geomorfologija in geoekologija. Zbornik referatov 5. znanstvenega posvetovanja geomorfologov Jugoslavije*, pp. 45-54.
ZOGOVIĆ, D. (1966). Hidrogeološka uloga dolomita u dinarskom karstu. *Vesnik, inženjerska geologija i hidrogeologija*, 6, 5-112.
ZORN, M. (2002). Rockfalls in Slovene Alps. *Geografski zbornik*, 42, 123-160.
ZUPAN HAJNA, N. (2002). Chemical weathering of limestones and dolomites in a cave environment. In: Gabrovšek, F., ed. *Evolution of karst: from prekarst to cessation*. Ljubljana (ZRC SAZU), pp. 347-356.

Blaž K o m a c, Matej G a b r o v e c

NIEKTORÉ VLASTNOSTI DOLOMITICKÉHO RELIÉFU V SLOVINSKU

Väčšina dolomitov v Slovinsku, ktoré pokrývajú 2500 km^2, čiže 11,7 % celkovej rozlohy vznikla dolomitizáciou vápenca. Stratigraficky rozlišujeme 12 typov dolomitov, pričom najčastejšie sa vyskytuje mezozoický dolomit a konkrétne dolomit z triasu. Podiel dolomitických oblastí v Slovinsku je najväčší v Dinárskej krasovej oblasti, kde pokrýva pätinu povrchu a vo vysokohorských oblastiach, kde pokrýva šestinu povrchu. Dolomitický reliéf je pestrý. Vo vysokohorských oblastiach sa často vyskytujú steny a strmé svahy s výmoľovou eróziou. Reliéf s úvalinami sa v Slovinsku vyskytuje často, ale skutočné krasové povrchy sú na dolomitoch zriedkavé. Časté sú prechodné oblasti s fluviálno-denudačnými vlastnosťami a krasovými povrchmi. Na ich pomenovanie sa používa termín fluviokras, ktorý však z hľadiska genézy nie je priliehavý.

Autori opisujú hlavné vlastnosti dolomitického reliéfu v Slovinsku a venujú zvláštnu pozornosť dvom dolomitickým oblastiam: Žibršeckej planine a pahorkatine Polhov Gradec. V oboch týchto oblastiach sa uskutočnil geomorfologický terénny výskum, pri ktorom sa zistili nové dôkazy o vlastnostiach a intenzite formovania či premien dolomitického reliéfu.

Žibršecká planina leží na kontakte vrchov Rovtarsko hribovje na severe a dolinovom systéme Notranjska na juhu. Južná časť vrchov, ktoré nesú meno blízkej dediny Logatec je budovaná zväčša z dolomitu. Ich reliéf je zaujímavý pre svoju štruktúru a blízkosť idrijského zlomu, prechodnú povahu litologickej štruktúry, v ktorej sa strieda dolomit a slieň, hydrogeografické pomery a rôznosť geomorfologických procesov. Výskum potvrdil nepopierateľnú geomorfologickú úlohu vody, ale aj príslušných vzťahov medzi

erózno-denudačnými procesmi a koróziou. Určité vlastnosti dolomitického reliéfu naznačujú, že dnes je korózia významnejšou reliéf formujúcou silou ako erózia alebo denudácia. Na jej intenzitu vplýva aj červenozem, ktorá sa zachovala na dnách úvalín a prehĺbenín na Žibršeckej planine. Úvaliny sú charakteristickou črtou oblasti a ich svahy brázdi veľa úvozov, ale závrty sú s výnimkou horného okraja svahov nad riekou Reka na severe skôr zriedkavosťou.

Okrem geomorfologických podmienok a vlastností horniny, ovplyvňuje vývoj povrchu aj tektonika. Pozdĺž zlomov je hornina popraskaná a rozdrvená. Rozmiestnenie úvalín závisí na dráhach vnútorných častí zlomov. Zdá sa, že tektonika zohráva veľkú rolu aj v tvorbe sediel, dolomitických pahorkov, ihiel a krasových polí. Ak je dolomit karbonátového pôvodu, podlieha korózii. Pri meraní tvrdosti vody v potoku na Žibršickej planine sa zistilo, že korózia, ktorá znižuje povrch, je relatívne rýchla [120 $m^3/km^2/a$ (m/ka)].

Dolomit je náchylný na rozpad pozdĺž tektonických deformácií. V takých oblastiach je povrch často holý a trpí silnou denudáciou. V pahorkatine Polhov Gradec (Polhograjsko hribovje) na západ od Ljubljany je dolomit silne popraskaný v dôsledku zlomov a prekrytia vrstiev. Merania uskutočnené v roku 2002 ukázali, že na strmých holých dolomitických svahoch je intenzita denudácie až 170t/ha. Zistilo sa, že dolomitický reliéf v Slovinsku sa formoval pod vplyvom gemorfologických procesov v štvrtohorách. V niektorých oblastiach sa dolomitický reliéf dramaticky menil počas chladných období v dôsledku periglaciálnych procesov (Žibršická planina). Naproti tomu na iných miestach ho ovplyvňujú procesy intenzívnej geomorfologickej premeny, ktoré predbiehajú v súčasnosti (pahorkatina Polhov Gradec). Ak je dolomit karbonátovej povahy, podlieha aj mechanickému zvetrávaniu. Dolomity sú zaujímavé aj z hľadiska štúdia geomorfologických procesov a foriem reliéfu. Výskum dolomitického reliéfu azda prispeje k pochopeniu tak fluviálneho ako aj krasového reliéfu. Preto autorov prekvapuje nízky počet štúdií, ktoré sa venovali tejto problematike.

Preložila H. Contrerasová