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Karst Geomorphology

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DOLINES, THEIR MORPHOLOGY AND ORIGIN. CASE STUDY: DOLINES FROM THE KRAS, WEST SLOVENIA (THE ŠKOCJAN KARST)

ABSTRACT: MIHEVC A., *Dolines, their Morphology and Origin. Case Study: Dolines from the Kras, West Slovenia (The Škocjan Karst).* (IT ISSN 0391-9838, 1998).

The doline forms from the levelled karst surface in the SE part of the Kras plateau, between the cave system, Škocjanske jame, and the village of Divača, W Slovenia are described. There are 776 dolines in the area. Most of them are small, up to 50 m in diameter and up to 5-8 m deep. Fifteen per cent of the dolines are medium-sized, having diameters of 100-200 m and depths of up to 30 m. The largest dolines are believed to be of collapse origin. These have a total volume of about 38 x 10^6 m^3, comprising 15 large depressions which are 200-400 m in diameter and 30-80 m deep. The largest collapse doline, the 122 m deep Dol Sokolak, has a volume of 8.5x10^6 m^3. Within the same territory there are 662 smaller dolines with a volume about 6-10x10^6 m^3. In small areas, doline density reaches up to 240 per km^2. The density depends on several factors, particularly on the properties of rocks, the dip of slopes and the size of the dolines.

The dolines vary greatly in their morphology and origins there are solution dolines, «inherited dolines» which were formed by exposure of underground caverns by surface erosion, and two types of collapse dolines.

KEY WORDS: Geomorphology, Karst, Doline, Kras, Slovenia.

DESCRIPTION OF THE AREA

The described area has 31 km^2 of karst surface and is situated in the SE part of the Kras plateau (46° 36' N, 13° 59' E), between the borders of the river Reka and the village of Divača. It will be referred to as the Škocjan karst. Cretaceous thickbedded limestones are the major outcropping rock, and they are bounded in the S and NE by Palaeogene thinbedded limestones. Karstification of the terrain started after the Oligocene, when the entire Kras area was uplifted, folded, and exposed to intense tectonics. A process which has been taking place within the frame of the Alpine orogeny up to the present day. The central part of the area is located between 420 and 450 m a.s.l. and slightly inclined towards the NW. The dips of the surface are low, below 10°. The bedrock exhibits higher dips on the margins which ascend towards an area of low hills, and in some dolines.

The average annual temperature of the area is 9°C, and the average annual rainfall about 1,400 mm. The primary rainfall maximum occurs in November, the secondary in June, August being the only dry month. The natural vegetation is forest. The woodland had been deforested and transformed into pastureland by the Bronze Age. At present the terrain is pasture and woodland.

In the area, the soils are shallow and of brown rendzina type. The surface soil is discontinuous and the major part of the surface displays grikes and clints. Thicker soils can be found in the doline bottoms, where chromic cambisol soil is developed on loam fills.

The area reflects a long period of karst development. All of the precipitation water sinks directlty into the karst. The topography does not show any traces of surface river networks. On the eastern side, the allogenic river Reka sinks into the cave system of Škocjanske jame at 317 m a.s.l. This large sinking river causes large oscillations of the water level in the passageways of the caves. In Škocjanske jame, water rises by some 90 m (Mihevc, 1983). The underground Reka may be followed as far as the terminal sump at 214 m a.s.l. in Škocjanske jame, and then reappears in the NW, in the Kačna jama at an elevation of 195 m a.s.l. and disappears at 156 m a.s.l.. It is believed that there is an approximately 150-280 m thick vadose zone underlying most of the Škocjan karst. In the area, 67 caves are known, the deepest of which are Kačna jama (280 m), Škocjanske jame (250 m), and Mejame (173 m). The

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total passage length of all the known caves is 21,782 m. The majority of active river passages are Škocjanske jame and Kačna jama.

In the Škocjan karst, the most common surface landform is a closed circular depression called a doline (in the Slovenian language termed «dolina» or, when bigger, «dol»). Within 31 km^2 of the Škocjan karst (fig. 1), there are 776 dolines which represent 12 % of the total surface. 80% of dolines are small (up to 50 m in diameter and up to 5-8 m deep), 15 % are medium-sized (100-200 m in diameter and up to 30 m deep), and 5 % of them are large depressions (200-400 m in diameter and 30-80 m deep). On average there are 25 depressions per km^2. In some areas the density of dolines is up to 240 per km^2 The highest concentration of dolines is on Cretaceous limestone. Dolines rarely occur on Palaeogene limestone and on slopes of more than 15^0.

By comparing the Škocjan karst with the remaining part of the Kras, the number and density of small and medium-sized dolines are the same in both cases, exceptional only is the proportion of large dolines. The large dolines of the Škocjan karst are developed in two elongated sets close to and either side of the underground Reka (fig. 1).

The morphology and distribution of dolines were examined by Habič (1978). Gams (1992) studied land use and anthropogenic changes in the karst. Much attention was directed to individual large collapse dolines (Gams, 1983), who established that their collapse origin and association with the Reka river's underground flow.

ORIGINS OF THE DOLINES

Dolines may be categorised by their morphology and morphometry, but their genetic origin cannot be easily deduced from their dimensions or shape. In recent years, new discoveries in caves, and construction of a highway that cut through many dolines and enabled identification of some of the dolines genetic origins.

Solution dolines – Most of the dolines in the area are assumed to be solution dolines. They are developed as surface features of the epikarst zone due to locally more intense solution (Williams, 1985). Their shape, particularly that of their cross sections, highly depends on local lithological and structural conditions. The solution dolines are mostly shallow, up to 8 m deep. Most of them have a volume of some thousands to several tens of thousands of m^3. Their sides are covered by a similar type of soil to that on the surrounding surface. In the bottoms of the dolines there are mostly several-metre-thick loams covered by brown soil.

During the previous centuries, most of the dolines were subjected to intensive agriculture resulting in only small amounts of soil being preserved in the some doline bottoms. Clearing of the region by removing or cutting stones from the surface placing them in mounds or using them for the construction of dry walls was a normal practice in preparing the karst for agriculture (Gams, 1992).

The construction of a major highway throught the karst has allowed some characteristics of the solution dolines to be established. The concave doline bottoms are covered with red-brown loams, and overlain by humic soils which contain fragments of prehistoric pottery and pieces of charcoal. The humic soils were washed down the doline slopes as a result of the burning of forests and their conversion into pasture. Despite these several-metre-thick loams and soils in the doline bottoms and the presence of the deep vadose zone below, suffosion funnels, connecting the two, rarely occur.

Unroofed caves - «inherited dolines» – Some of the features that in the past have been classified as solution dolines, contain fluvial sediments and secondary cave minerals such as flowstones establishing that these dolines were either previously open shafts or underground cavities that have lost their roof. In either case, most of the rock was removed by speleogenetic processes.

A number of dolines in the path of the highway construction had been formed from infilled shafts. On their steep slopes, remains of flowstone are found, and in the bottoms are fills some tens of metres thick. In other parts of the area it is difficult to prove this genetic origin, as there it is no real evidence of the former cavity or the thickness of the sediment in the bottoms of the dolines.

It is easier to prove the inherited origin of dolines if the original cavities were cave passages rather than shafts and the cave passages were filled with allochthonous sediments (Habič, 1992; Mihevc & *alii*, 1996). The process of removing the roof above a cave is slow and is a consequence of denudation of the surface. The roof above the cave is completely thinned and disintegrates into individual blocks which are quickly decomposed by solution. Above the cave sediments a concave relief feature is formed, since the sediments are no longer protected by the roof from precipitation and washing into the deeper parts of the karst.

The origin of these «inherited» dolines can be proved by the existence of flowstone and of sediments characteristic a cave environment. In the Škocjan karst, such dolines are often elongated or arranged in a line. The largest such group is 1,800 m long consisting of several elongated depressions which were formed from an approximately 20 m wide cave passage. At the end of such groups of depresions small caves or shelters may be found.

Dolines of this origin occur relatively frequently. Within the Škocjan karst some tens of such «inherited» dolines have been identified.

Collapse dolines – the formation of a doline by collapse into a cave. Cave roof collapse is a slow process which proceeds by breaking of the walls until equilibrium is established on the slopes of the doline (Šušteršič, 1973). As a rule, the volume of the newly formed feature, doline, is smaller than the cave it collapsed into, since the collapsed rock occupies a larger volume than the solid rock. Most of the known cave chambers within the area have dimensions up to some 10,000 m^3, therefore it is expected that the dimensions of chambers that fomed the collapse dolines will be a similar order of magnitude.

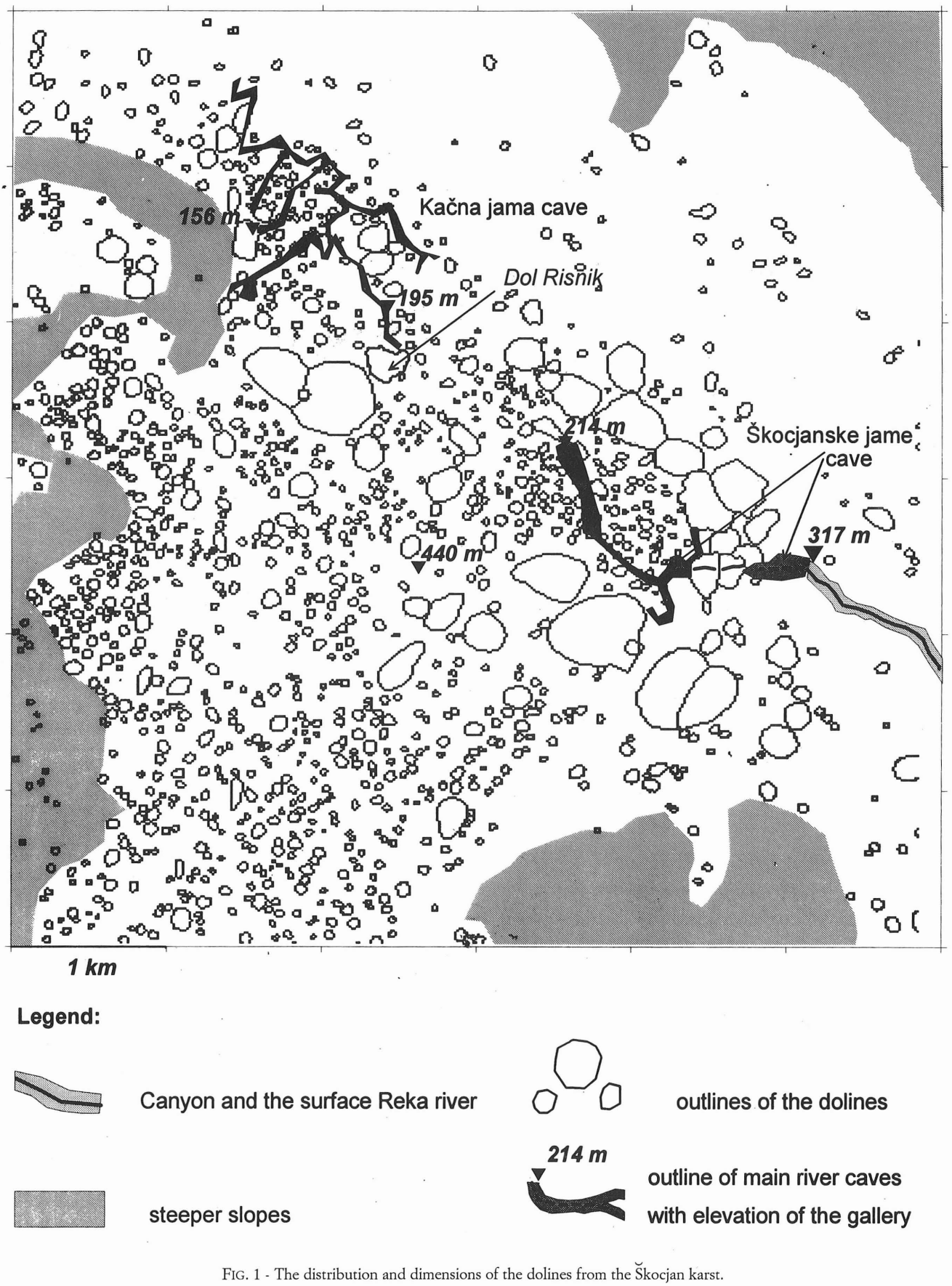

FIG. 1 - The distribution and dimensions of the dolines from the Škocjan karst.

FIG. 2 - A doline which was formed above an infilled shaft. During the highway construction, the top soil was removed and the double structure of the doline was exposed. The upper part was fomed by slope processes and solution in the subcutaneous zone of the karst. The lower, in cross section more irregular part is the remnant of a solution shaft filled with sediments. The circumference of the doline is clearly distinguished from the irregular cross section of the shaft which is filled with loam.

FIG. 3 - An elongated doline which was formed by the interaction of denudation surface and a cave. In the bottom of the «inherited doline», sediments are allogenic,characteristic of the cave environment. The doline was formed by partial removal of the cave fill and the conversion of the cave walls into doline sides.

In the Škocjan karst some dolines origin can be clearly attributed to collapse, such as those which lead into large caverns, or those with steep or vertical slopes and with bottoms covered by cave sediments or collapsed blocks. Dolines developed by simple collapse of underground cavities must be smaller that the cavities themselves, and they would fall into our category of inherited features.

Within the Škocjan karst, there are several dolines which with regard to their morphological features and sediments are evidently of collapse origin, but their dimensions are by two orders of magnitude larger than the volumes of the largest currently known caverns. It is evident that the large collapse dolines were formed by transformation of underground cavities into surface features by collapse and wall or slope retreat, but their immense dimensions are mainly the result of the removal of disintegrated collapsed rock at depth, via solution by the underground rivers. Thus the volumes of these collapse dolines are larger than the volumes of the pre-existing cavities, and many collapse dolines continue to grow with time.

Such large dolines can be found above the underground course of the Reka, and they are particularly well-developed in the area of Škocjanske jame. Velika dolina and Mala dolina are the 150 m deep collapse dolines through which the Reka flows at the bottom. Above the old passages of Škocjanske jame, the collapse doline Lisična has developed. It is 100 m deep and 350 m in diameter. The largest cave chamber in the karst is the Martel Chamber in Škocjanske jame. It is 123 m wide and 146 m long, and has a volume of 2.1×10^6 m^3. The thickness of the roof is about 100 m (Mihevc, 1994). The chamber was formed by the underground Reka with its average annual flow of 8.3 m^3/s. In it 132 m oscillations of water level by can be observed. The Martel Chamber will with time become a collapse doline.

A second requirement for the formation of large collapse dolines is a suitable geological structure, such as tectonically broken zones within the rock. In the Škocjan karst, sets of parallel vertical fissures are of great importance (Kranjc & *alii*, 1992). Since they intersect major water routes underground they can form large caverns or sets of smaller, parallel caves. In the large breakdown chambers before collapse, rock breakdown is observed along tectonic fissures which also show evidence of solution. Solution is both a consequence of infiltrating vadose water and the oscillation of the piezometric water level.

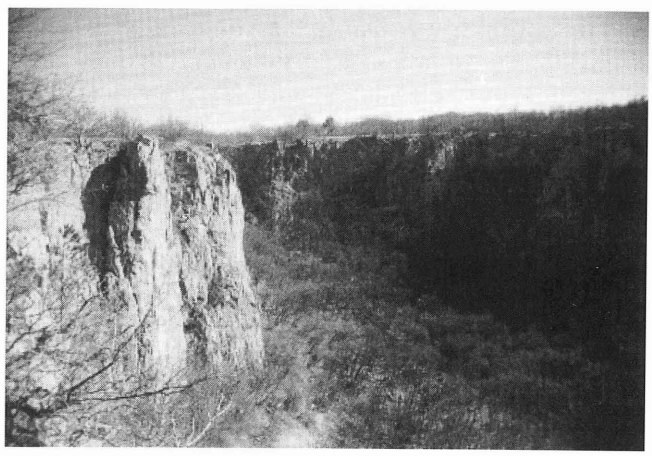

FIG. 4 - The collapse doline Risnik. It was formed on a levelled surface. The bottom is about 170 m above the present Reka course in the passages of Kačna jama.

In the case of three collapse dolines within the Škocjan karst, Bukovnik, Risnik, and Dol Krgunce, stream and river cave passages lead below the collapse dolines. However, the bottoms of all the three collapse dolines are more than 100 m above these active passages and now beyond the reach of flood waters.

In the area there are 15 large collapse dolines, having a total of about $38x10^6$ m^3. Within the same territory there are 662 smaller dolines with only about $6\text{-}10x10^6$ m^3. The largest collapse doline is the 122 m deep Dol Sokolak, having a volume of $8.5x10^6$ m^3. Dol Globočak is smaller, 90 m deep and has a volume of $4.8x10^6$ m^3. Dol Risnik is 86 m deep and has a volume of $1.4x10^6$ m^3.

The mechanisms of the formation of large collapse dolines are not well understood, but vertical fracturing, solution along fractures, extensive oscillations of the piezome-

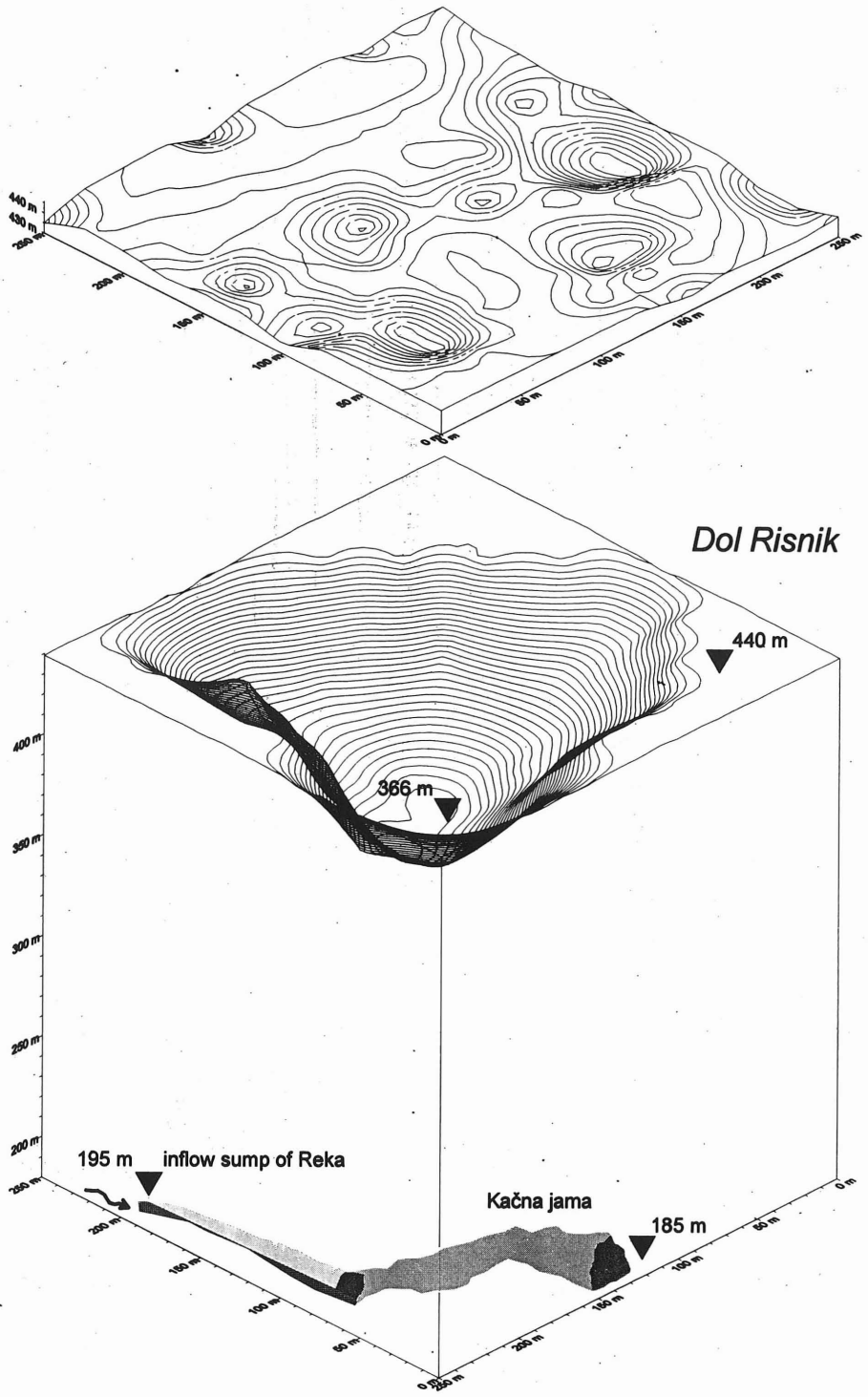

FIG. 5 - A comparison of the land surface of 250 m x 250 m containing dolines with the area of the same extent containing the collapse doline Dol Risnik.

tric water level and the vicinity of important conduits are known to be necessary for their formation. It is particularly important that the initial collapse starts when the stream creating the cave is still present in the vicinity.

CONCLUSION

The most frequent surface karst landform in the Kras area is the doline. During the mapping of the surface it is difficult or even impossible to determine their genetic origin. This was confirmed when a detailed study of dolines made possible by extensive highway construction clearly indicated that surface observations alone cannot determine the genetic origin of dolines.

A large number of «inherited» dolines were formed by interaction of underground cavities and the epikarst zone. The dolines were only partially created in it. The major part of the volume of the rock was removed previously, at greater depth, in the phreatic or the epiphreatic zone of the karst. It is almost impossible to say what is the proportion of such cavities. During the highway construction, the remains of caves were noticed in about one third of the dolines.

It has been established that the collapse dolines were formed in two ways. Some of them are the result of the collapse of old, nonactive caves. This process creates small collapse dolines having volumes which are smaller that those of the pre-existing cavities. In some cases, these dolines form collapse entrances to caves.

The collapse dolines of exceptional dimensions, with volumes of which surpass the volumes of all the known underground caverns in the area, could have been formed, or are being formed, by rockfall into cavities and subsequent removal of the rock. This conclusion is supported by by the distribution of the dolines along the underground course of the Reka.

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