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ON THE FORMATION OF KARST DOLINAS

With 4 text-figures

The opinion of the two-phase formation of the dolinas is put forward; initial depresions in the relief were caused by collapse and were later transformed into dolinas in their present shape by corrosive processes.

One of the main morphological characteristics of karst areas are dolinas. Their frequency of occurrence, their shape and size have been reasons why many authors have attempted to explain the origin of these forms. According to Cvijić (1960), the main upholders of the theory of the corrosive origin of the dolinas were Mojsisovics, Sawkins and others. Later, the same opinion was put forward by Gorjanović (1912), Terzaghi (1913), Lehman (1931), Poljak (1957) and Baučić (1961). Cvijić (1960) also states that Tietze, Schmidl, Kraus and Putick, in contrast to the above mentioned authors, consider that the origin of dolinas is a result of collapse. However, each of the theories mentioned above presumes the existence, formerly, of rather different natural conditions to explain the formation of dolinas. Thus the formation of dolinas due to corrosive processes alone, indicates implicity that the formation process occurred and is still occurring from the surface downwards. For this, beside limestone or dolomitic rock also a soil cover would be necessary, which might have instigated the corrosive processes. On the other hand, the theory of the formation of the dolinas simply by collapse, assumes the existence of an underground cavity into which the material has been collapsed. Thus, underneath each dolina a cavity must be supposed to have existed, the size of the dolina depending upon the size of the cavity.

Both explanations, however, ignore the characteristics of the material in which the dolinas are formed. Consequentl, a number of geological and hydrogeological factors concerning the rock before the existence of the dolinas, i. e. before the existence of a loose soil cover, or before the collapse, have not been taken into account. Therefore we intend to make

here a short review of the geologic conditions which might have influenced the development of the dolinas, taking into consideration both the previously mentioned theories.

Neogene deposits overlying Mesozoic rocks can be found troughhout the northeastern parts of the Dinaric Karst region (e. g. between Karlovac and Slunj in Central Croatia). The morphology of the paleorelief ot fhis area displays all the characteristics of a typical karst region: fossil dolinas, jointed limestone, large fissures widened by solution, and holes filled up with Neogene deposits and so »preserved«. This means that the Karst phenomena were formed before the Neogene and that further development of these forms vas interrupted by the deposition of clastic Neogene deposits. In the other regions, which were not under water at that time, the karstification processe continued uninterrupted. Consequently, one comes to the conclusion that a proportion of the recent dolinas represents nothing else but a temporary continuation of that ones originated before the Neogene. Accepting present-day geological conditions we may assume that the lower temporal boundary of the beginnig of the continental phase, i. e. the beginning of karstification in the Dinaric karst, should be placed somewhere after Cretaceous and before the end of the Eocene. Or, more exactly, that boundary coincides with the beginning of an intense phase of mechanical activity which led to the formation of vast talus material consisting predominantly of carbonate fragments. Such material is the main component of the Jelar-deposits (B a h u n, 1963), which were probably formed in the Late Paleogene (P o l š a k, 1957, C r n o l a t a c & M i l a n, 1959). So we come to the question of the relationship between the corrosive formation of the depressions and the mechanical and chemical lowering of the relief. Due the lack of data to explain that problem, it is necessary to examine all the causes which might have lead to the formation of a depression in the relief. The time factor should also be taken into account. Thus, the following possibilities appear presumable:

– that the corrosive deepening of the dolinas progressed faster than the lowering of the relief, or

– that the corrosive deepening of the dolinas and the lolering of the relief progressed at the same speed, or

– that the lowering of the relief progressed faster than the corrosive deepening of the dolinas, or

– that primarily (during the first phase) the corrosive deepening of the dolinas took place, and afterwards (in second phase) lowering of the relief began, or

– that the lowering of the relief took place in the first phase, and afterwards (in the second phase) the dolinas were deepended.

Now, if we want to explain the formation of the dolinas by corrosive processes only, the hypotheses that the lowering of the relief has progressed faster, or has occurred after the corrosive action, can be eliminated. This is obviously also the case if both processes progressed at the same speed. In these cases dolinas could not be formed, because the bottom of a dolina should reach below the level resulted in by the lowering of the relief. The first of the mentioned hypotheses, i. e. that the corrosive deepening has progressed faster than the lowering of the relief, anticipates the formation of the dolinas by corrosive processes starting immediately after the establishment of the first carbonate dry-land. In the investigated area, this is to be understood as not later than the Late Eocene. Due to the lowering of the relief, dating from that time, present-day dolinas would represent, in fact, nothing else but remnants, i. e. lower parts of considerably larger ancient »funnels« whose upper parts had been destroyed by the lowering of the relief (Text-fig. 1). However, this possibility either can be refuted, if we

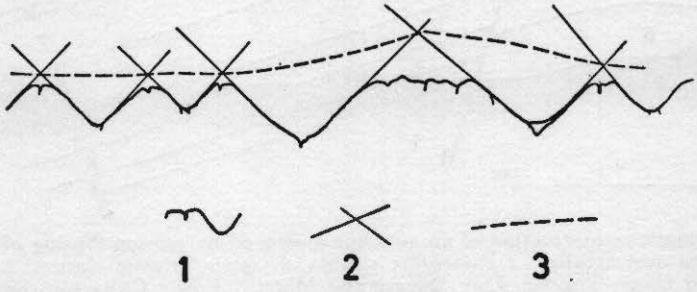

Fig. 1. Schematic reconstruction of the decrease in the diameter of dolinas caused by erosive lowering of the relief. Present-day cross-section of the dolina, *2* Prolongation of the slopes, *3* Former surface on which the hollowing caused by corrosion colud have started.

Sl. 1. Shematizirana rekonstrukcija sužavanja promjera ponikava uzrokovanog erozivnim snižavanjem reljefa. *1* današnji profil ponikava, *2* produženi strana, *3* nekadanšja površina s koje je trebalo početi udubljavanje uvjetovano korozijom.

take into account that an intense phase of mechanical activity towards the end of the Paleogene, and during the Neogene and Pleistocene took place. For that period deposits reaching in some places more than 2,000 m in depth wuold have to have been removed (Text-fig. 2).

The last possibility remains: – that the dolinas were formed, the relief having been already considerably lowered, i. e. in the final phase of the formation of the present-day relief. However, considering the development of geological conditions from the end of the Eocene till to-day it is necessary to take into account, besides the corrosive processes, the hydrogeological properties of rocks in which the dolinas are formed.

According to all modern authors, the formation of karst features in carbonate sediments began immediately after these sediments became dry-land and exogene factors started to affect it. In the investigated area that occured not later than the beginning of the Oligocene. From that time till to-day the carbonate rocks have been exposed to all kinds of denudation processes on the surface, as well as to mechanical and chemical decomposition underground, except the parts of the area which were covered over with Neogene deposits. However, because of the permanent

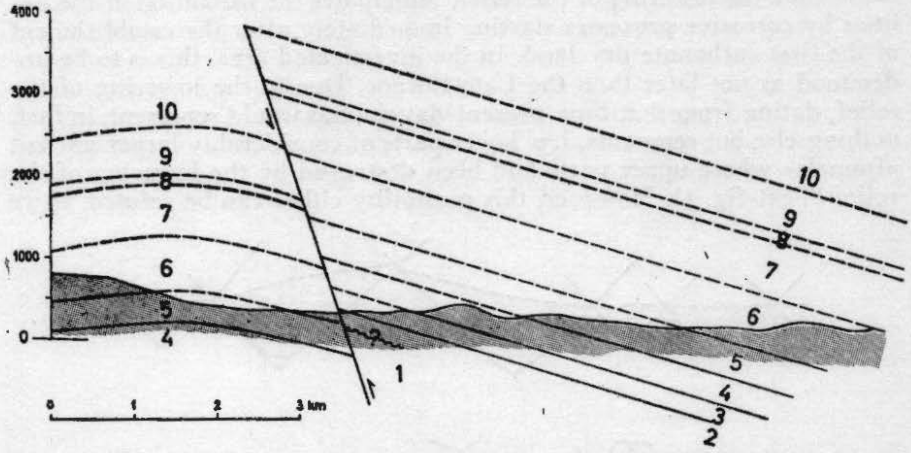

Fig. 2. Schematic reconstruction of an anticline destroyed by erosion (Spring of Zagorska Mrežnica near Ogulin). *1* Palaeozoic clastics, *2* Upper Triassic clastics, *3, 4, 5, 6* Dolomites of Upper Triassic, Lias, Dogger and Malm, *7* Lower Cretaceous limestones, *8* Dolomites and dolomitic breccias of Upper Cretaceous, *9* Limestones with Rudistids-Cennomanian and Turonian, *10* Limestones with Rudistids-Senonian.

Sl. 2. Shematizirana rekonstrukcija erozijom razorene antiklinale (izvor Zagorske Mrežnice kod Ogulina). *1* klastiti paleozoika, *2* klastiti gornjeg trijasa, *3, 4, 5, 6* dolomiti gornjeg trijasa, lijasa, dogera i malma, *7* vapnenci donje krede, *8* dolomiti i dolomitne breče gornje krede, *9* vapnenci s rudistima cenomana i turona, *10* vapnenci s rudistima senona.

lowering of the relief the surface forms were unstable and of short duration, while in the carbonate underground the cavites were constantly enlarging due to erosive and corrosive action of water. In tectonically more disturbed regions water can more easily and quickly reach a lower level, forming at the same time a network of underground channels and open fissures. By the way, the decomposition of carbonate sediments has been carried out in two directions: vertically, by the lowering of the relief; and horizontally, by the formation of underground openings through which the circulation of underground waters has been established. As a result of these destructive factors, the existing underground hollows be-

came visible when they came near to the surface, due to the lowering of the relief. With the collapse of the roof swallow-holes and caverns were formed – i. e. morphological features which may be considered initial stages in the formation of dolinas. Both, the inclination angle of the slope which depends upon the properties of the rock, and the corrosive processes determine the definite shape of such a depresion (Text-fig. 3).

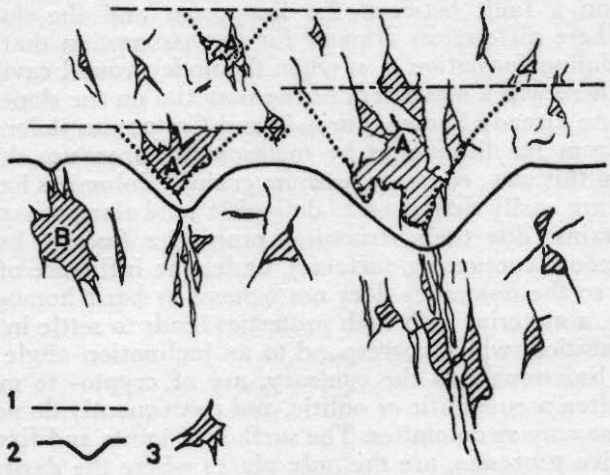

Fig. 3. Schematic reconstruction of the origin of the initial depression preceding the formation of a dolinas. *1* Phases of lowering of the relief, *2* Recent surface, *3* Cavities and fissures, *A* Cavities from which the dolinas originated, *B* Cavity preceding the origin of the dolina.

Sl. 3. Shematska rekonstrukcija postanka inicijalnog udubljenja koje prethodi stvaranju ponikve. *1* faze snižavanja reljefa, *2* današnja površina, *3* šupljine i pukotine, *A* šupljine iz kojih su nastale ponikve, *B* šupljina koja će prethoditi stvaranju ponikve.

To support that idea, the following field observations on the distribution and shape of the investigated area, should be presented here:

a) Concentration of dolinas in areas disturbed by faults, or these arranged in rows at fault-zone, could be explained by the fact that the tectonically predisposed directions enabled an easier circulation of water, corrosion of the jointed rocks, and forming of underground cavities of various shape and size. The lowering of the relief would produce a greater amount of collapsing at places with abundant underground cavities, and in this way dolinas would be formed.

b) The same conditions caused the formation of a larger amount of dolinas in depressions, than on sloping ground or upland areas.

c) Comparing the dolinas in the dolomite and the ones in the limestone, considerable differences are revealed. Dolinas in the dolomite have usually a more regular shape, their slopes being more gently inclined, and often they contain no great amount of loose material. On the contrary, dolinas in the limestones show an irregular shape, steeper slopes (sometimes even a cascade-like profile), and usually there is more loose material on their bottom. These differences can be clearly seen in the dolinas situated on a fault between the limestones and the dolomite (Text-fig. 4). These differences account for the assumption that in the initial stage of doline-formation, i. e. when the underground cavities have been opened, there was a movement of the material on the slopes due the gravitation. As already known, Jurassic and Cretaceous dolomites have originated from the limestones by metasomatic processes during the diagenesis. In this way, coarse to medium grained dolomites have been formed which are easily destroyed to dolomitic sand along the contact surfaces of the grains, due their structural properties (mostly hypidiomorphic grains, smooth connecting surfaces), under the influence of exogene factors, and so the dolomites does not behave as hard homogeneous rocks. Certainly, a material with such proterties tends to settle in the most convenient position, which correspond to an inclination-angle of about 30°–40°. The limestones, on the contrary, are of crypto- to microcristalline texture, often pseudoolitic or oolitic, and consequently do not disintegrate in the same way as dolomites. The surface of joints and fissures, widened by corrosive processes, are the only places where the destructive process can take place. For this reason the dolinas in limestones have considerably stepper slopes, sometimes even vertical, and the slopes are often rugged with rock-blocks. At the same time, this explains why dolinas have a rounded, funnel-like shape, which can be clearly seen in present-day dolines, originating in Quarternary deposits. As regards the secondary material, which has been carried off from the slopes and deposited on the bottom due to gravitation, it suffers a more intense destruction because of its looseness, and is later definitely evacuated through the bottom of the dolina.

Finally, it should be emphasized that the relationship between the corrosive and mechanical processes in the formation and shaping of dolinas can not be defined, and the observations given in the present paper do not intend to oppose in principle existing opinions. On the contrary, the present observations should be considered an addition to the explanation of the formation of karst phenomena and the aim of the paper is to initiate a critical analysis both of the general principles and of the concrete relationships in the field.

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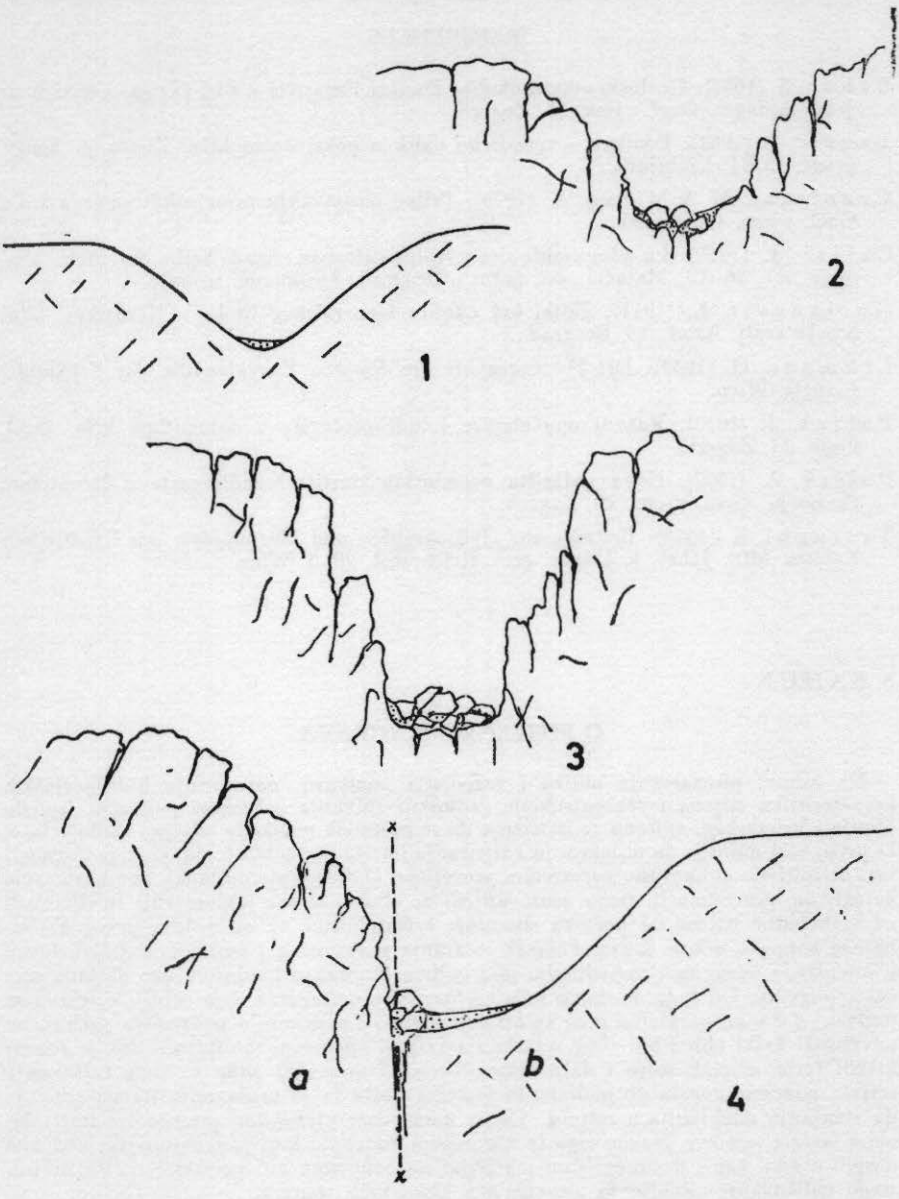

Fig. 4. Different shapes of dolinas. *1* Dolina in dolomites, *2, 3* Dolinas in limestones, *4* Dolina on the fault between Cretaceous limestones *(a)* and Malmian dolomites *(b)* – Primišlje near Slunj.

Sl. 4. Različiti oblici ponikava. *1* ponikva u dolomitima, *2, 3* ponikve u vapnencima, *4* ponikva na rasjedu između vapnenaca krede *(a)* i dolomita malma *(b)* – Primišlje blizu Slunja.

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O POSTANKU PONIKAVA

Na osnovi promatranja oblika i rasporeda ponikava, poznavanja hidrogeoloških karakteristika stijena i rekonstrukcije geoloških zbivanja u krškom području između Slunja i Vrbovskog, opisano je mišljenje da se postanak ponikava odvijao u dvije faze. U prvoj fazi došlo je do urušavanja i stvaranja inicijalnog udubljenja, koje je u drugoj fazi definitivno oblikovano korozivnim procesima. Objašnjenje postanka ponikava samo korozivnim procesima ili samo urušavanjem ne obuhvaća sve faktore koji su djelovali na karbonatne stijene od početka stvaranja krških formi, tj. od pojave prvog karbonatnog kopna u nekom kraju. Početak stvaranja površinskih i podzemnih krških formi u intenzivno boranim i rasjednutim područjima (kojima pripadaju i ove oblasti) seže čak u oligocen. Od tada do danas su u karbonatnim naslagama, čija debljina uglavnom prelazi i 2.000 m, paralelno tekli snižavanje reljefa i razgradnja podzemlja, tako da su površinski krški oblici bili zbog snižavanja reljefa opetovano uništavani dok je razvoj krških formi u podzemlju i dalje napredovao. U momentu kada je zbog snižavanja reljefa površina doprla do podzemnih šupljina došlo je do urušavanja terena odnosno do stvaranja udubljenja u reljefu. Takvo udubljenje vjerojatno predstavlja inicijalni oblik buduće ponikve. Nakon toga će sekundarni materijal koji je gravitacijski s bokova dospio u dno, kao i dezintegrirani materijal na bokovima biti pripremljeni za definitivno oblikovanje udubljenja posredstvom korozivnih procesa.

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