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Bedding-plane anastomoses as one of the early stages of karst evolution

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ABSTRACT:

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Bedding-plane anastomoses are braided channels of oval cross-section, connected in networks. They form along limestone bedding planes, in the lower surfaces of upper beds. Reasons for their upward growth are still not clearly defined. Preliminary experiments, based on the assumption that bedding planes in which anastomoses occur are cycle boundaries, were carried out on several samples, as a suggestion for the further research of this problem. The sampling was carried out at anastomoses profiles in cave walls, while performed experiments and analyses were: calcimetry, experimental dissolution, and analysis of thin sections. The results showed that the method of experimental dissolution of powdered samples had certain shortfalls because of the significant change of natural conditions, and that the further research should be directed primarily to calcimetry and analyses of thin sections.

Key words: Karst conduits, Bedding-plane anastomoses, Sedimentary boundaries, Experiments.

INTRODUCTION

Why is the growth of bedding-plane anastomoses bound only to the upper, overlying bed? Much is told about the evolution of developed cave conduits, but some simple questions, like this one, remain without definite solution. The answer to this question lies within the understanding of the processes which guide the evolution of the very first, tiniest conduits in limestone. Knowing how conduits behave at the earliest stages of their evolution, we might seek answers to more complex questions – why and how those conduits form, for instance.

MORPHOLOGY AND GENESIS OF BEDDING-PLANE ANASTOMOSES

Bedding-plane anastomoses, genetically and morphologically very interesting corrosional meso-forms in caves, are braided channels of oval cross-section, connected in networks which are visible in flat horizontal ceilings and collapsed boulders. Limestone bedding planes are subject to infiltration by water, which is the first phase, i.e. the necessary condition for the development of anastomoses. Their formation is more intense in those limestones which are not too much tectonically fractured, so the movement of groundwater depends on bedding. Flowing between beds under phreatic conditions, the water dissolves the limestone, but the corrosion mostly affects the bed above the bedding plane, while the bed below remains almost intact. The direct proofs of development of anastomoses in bedding planes are profiles exposed in the cave walls. In that case, both beds are visible – below and above a bedding plane, with anastomoses formed in the upper bed, i.e. in the lower surface of the upper bed. In the first phases of development, bedding-plane anastomoses have rounded cross sections, which later in many cases become elongated (elliptical), although they may

Fig. 1. Anastomoses network in Dudiceva Cave, Eastern Serbia

remain rounded and develop a so called “omega” shape. It is often the case that anastomoses form on several beds in a sequence, so every bed has a network of upward growing anastomoses on its lower surface. The result is to disrupt the stability of the beds and their eventual collapse. In this manner, great surfaces carved with anastomoses become visible. Collapsed material is in some cases washed away, or otherwise it remains on the place of collapse. This process can play an important role in cave passages development.

All authors who have studied bedding-plane anastomoses agree that these features form under phreatic conditions, with very slow movement of water, in a laminar flow condition without capability to transport solid materials. However, when it comes to definition of the reason for their upward growth, there is no unique explanation, but several hypotheses.

BRETZ (1942) was the first author to describe bedding-plane anastomoses, not only in caves but also on the surface – in the St Genevieve limestone formation on the cliffs of the Ohio River. According to BRETZ (1942), the reason for the upward growth of anastomoses lies in the existence of insoluble residue resulting from limestone dissolution. The residue settles to the bottom and protects the limestone below from solution. It cannot be washed away thanks to very slow movement of water, which is not capable of transporting solid materials. This theory seems to be convincing and logical, but it has not been proven experimentally or by calculation, so it still remains only an assumption.

The most complex analysis of this karst phenomenon was given by EWERS (1966), as a part of his research on the role of bedding in groundwater drainage. He carried out numerous experiments with salt blocks – with precisely calculated values of hydraulic head, duration of the experiment, inflow of water and space between the blocks, anastomoses networks were formed on the lower surfaces of the upper blocks. Shape and density of anastomoses are influenced by “small scale irregularities of the bedding surface” (EWERS 1966, p. 138). Ewers does not give a general explanation for upward growth of anastomoses, but only the explanation which refers to his experiment – in salt blocks, it is caused by the solution gradient (more concentrated solution accumulates at the bottom and protects the lower bed).

CURL (1966), by defining the conditions in which natural convection of water occurs, suggested that it could be the reason for upward enlargement of anastomoses. Density differences of water cause its downward movement along the conduit walls and upward return movement in the central parts, which brings fresh solvent to the ceiling and upper walls (an idea actually similar to that by Ewers, but much better elaborated). If the circulation of water through conduits is sufficiently slow, this process is possible even in case of very small density differences.

Small channels that resemble bedding-plane anastomoses, but in beds of marls and volcanic tuffs were described by CASTELLANI & CIGNA (1977). These features are probably formed in similar conditions to bedding-plane anastomoses in limestones – "such rocks have probably experienced a period of phreatic activity" (CASTELLANI & CIGNA 1977, p. 105).

It should be mentioned that, apart from bedding-plane anastomoses, there is also another type, which can be called "above-sediment anastomoses". They are formed as a consequence of filling of cave passages by sandy and clayey sediments (SLABE 1995). Anastomoses are formed by the water that flow in phreatic conditions between the sediment fill and the ceiling. After the sediment fill is washed away, anastomoses, separated by roof pendants, are visible in the ceiling. LAURITZEN (1981) proved the development of above-sediment anastomoses by experiments in plaster of Paris.

The greater number of previous investigations and papers on the characteristic upward growth of bedding-plane anastomoses argue that the existence of insoluble residues or density gradients in the water protect the lower bed from solution. However, there can also be different interpretations of the problem.

One possible explanation is the effect of petrological characteristics of limestones, which can, if combined with specific characteristics of this environment (phreatic) and flow regime (laminar), affect the differences in solubility of beds. The differences can be, for example, varying content of calcium carbonate, or texture characteristics (grain size, type of carbonate cement, etc.).

The mode of sedimentation can be one of the causes of those differences. Sedimentary boundaries are characterized by the presence of micritic limestone below and sparry limestone above the boundary – micrites are the final, regressive deposits of one cycle and sparry limestones are the first, transgressive deposits of the next cycle (LOWE 1992, p. 141). According to some research on limestone surfaces, sparry limestones are less soluble (permeable) than micrites (SWEETING & SWEETING 1969). However, LOWE (1992) states that underground conditions can lead to a different outcome – "...any water movement, acid generation and dissolution along the bounding bedding would be expected to exert much of their combined effect against the sparry bed above" (LOWE 1992, p. 141). If the bedding planes with anastomoses are at the same time sedimentary boundaries, it can be expected that this process influence their development up to a point.

To establish the influence of lithologic characteristics of limestones on development of bedding-plane anastomoses would require a lot of experimental work with great numbers of samples. Here are suggestions about what should be included in that research, as well as the results of the experiments carried out on several samples.

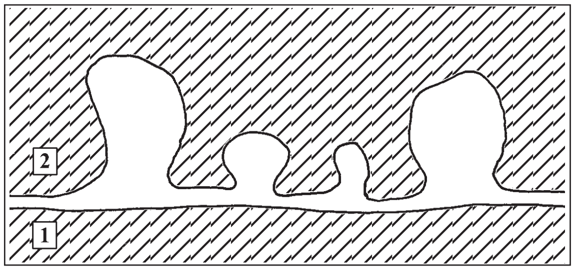

Fig. 2. The way of taking samples for research of bedding-plane anastomoses

METHODS

For the research on the bedding-plane anastomoses, it is necessary to take samples from both beds – above and below a bedding plane. Exact points of sampling are given the labels in letters (A, B, C), while beds are given the labels in numbers: 1 – bed below a bedding plane, and 2 – bed above a bedding plane. Thus, at each point, there is one pair of samples (Text-fig. 2). It is clear that sampling can be done only in case when there is an open profile, with both beds available. Anastomoses in cave ceilings and on collapsed boulders are not suitable for the experiments in which differences between beds are tested.

For the planned experiments (calcimetry and experimental dissolution), as well as microscopic analysis of thin sections, three pairs of samples were taken. The sampling was done in Eastern Serbia, in two caves formed in Upper Jurassic limestone. Two pairs of samples were taken from Dudiceva Cave in the gorge of the Zamna River: A1+A2 and B1+B2. This limestone is typically micritic. One pair of samples was from the cave Buronov Ponor on Miroc Mt. near the Danube Gorge: C1+C2. In this case, limestone was originally micritic, but strongly tectonically disturbed. Its fissures are filled with calcite, concentration of organic matter is relatively high, and there are also numerous stylolites.

The sampling was done so that from the beds labelled with No. 1, parts nearest to the bedding plane were taken. As for the beds labelled with No. 2, tips of the pendants were sampled.

Experimental dissolution of samples was carried out in order to detect differences in solubility of beds. 1

g of every sample (powdered) was put in 2 l of distilled water (respectively). The experiment lasted 11 days, while water analyses (concentration of Ca and Mg ions, by titration) were done twice, on 4th and 11th day.

RESULTS

Calcimetry gave the following results (Tab. 1): in all pairs, the samples labelled with No. 2, taken from the beds above the bedding planes in which anastomoses occur, have greater percent of calcium-carbonate than the samples labelled with No. 1 (below bedding planes).

It is interesting to compare these results with those presented by KNEZ (1996), which also state that average content of $CaCO_3$ in samples above formative bedding planes is greater than in the samples below.

According to the results of calcimetry, it was expected that the samples labelled with No. 2 would be more soluble than samples labelled with No. 1. However, experimental dissolution gave the results that were different than it was expected. Although on the 4th day concentration of Ca ions was bigger for samples No. 2 than for No.1, the relation changed on 11th day in favour of samples No. 1. Total concentration (Ca and Mg ions) was also bigger for the samples No. 1.

Sample	$\%CaCO_3$
A1	88,4
A2	89,2
B1	90,2
B2	91,4
C1	91,5
C2	93,0

Tab. 1. Results of calcimetry

Analysis of thin sections was also done for the three pairs of samples. Anastomotic networks occur in limestones of various petrologic characteristics, which explains their presence in great numbers of caves. In these samples, there were no significant differences between the beds on one location, but more detailed research in that direction should certainly be continued.

DISCUSSION AND CONCLUSIONS

The analyses and experiments described above are of introductory character, and can serve as a suggestion for one way of further research upon the development of bedding-plane anastomoses.

Regarding the used methods, it should be noted that there are certain shortfalls of the method of experimental dissolution of powdered samples. It is the fact that conditions in such experiments rarely correspond to natural conditions – there can be differences in chemical characteristics of water, elapsed time, water flow regime, etc. Powdering of the samples is a considerable change of the conditions, because micro-petrological characteristics are altered. Therefore the proper experimental dissolution should be done with compact pieces of rock, which would provide a proper contact of solvent and surface of the sample.

In further research it is necessary to work with greater numbers of samples, which would allow a certain degree of statistical interpretation, and to pay most attention to analysis of thin sections and calcimetry. Sampling is to be extended (on each sampling location) - along one bedding-plane, several pairs of samples should be taken, which would enable the comparison of parts in which anastomoses are present with those in which they are lacking. Analyses of thin sections would give better results if four (instead of two) thin sections are prepared for each pair of samples – two parallel to bedding-plane and two perpendicular to it. The latter would show possible change of micro-petrological characteristics of rock from the inner parts of beds towards a bedding-plane.

Although there is still more questions than answers, it is important to stress that understanding of development mechanisms of bedding-plane anastomoses will help us to better understand the early phases of karst evolution.

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