Upward Growth of Bedding-plane Anastomoses

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Abstract

Bedding-plane anastomoses are erosional forms of micro-relief in caves and represent one of the earliest stages of speleogenesis. The paper describes their basic morphological characteristics and attempts to define their genesis, but the question that arises is: Why is the growth of bedding-plane anastomoses bound only to the upper, overlying bed, while the bed below remains almost intact? All authors who made research on bedding-plane anastomoses agree that these features are among the earliest solutional cavities in karst and that they form in phreatic conditions, with very slow laminar movement of water, which is not capable of transporting solid materials. When it comes to explanation of their upward growth, there is still no definite answer, but when reached, it will help to understand the processes which guide the development of the very first, tiniest conduits in limestone.

Introduction

Much has been told about the evolution of developed cave conduits, but some simple questions, like the one about the reason for upward growth of bedding-plane anastomoses, remained without definite solutions. The answer to this question lies within the understanding of the processes which direct the development of first karst conduits. 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.

Basic Morphological Characteristics

Bedding-plane anastomoses are braided tubes along limestone bedding planes. They are connected in networks which are visible in flat horizontal ceilings and collapsed boulders, while cross sections can be found in cave walls. 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 is guided by 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 remain rounded and develop a so called "omega" shape. The size of the tubes is in most cases several centimetres to several tens of centimetres, but can, in certain cases, be measured in metres.

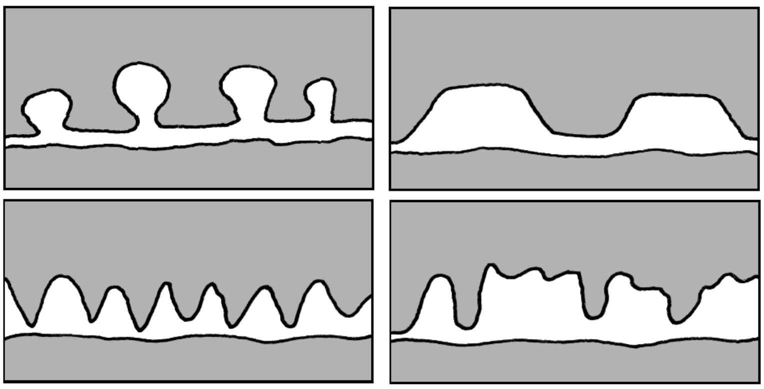

Figure 1: various cross sections of anastomoses

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.

Hypotheses on Upward Growth

It is broadly accepted that bedding-plane anastomoses 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.

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 (Fig. 2a). It cannot be washed away thanks to very slow movement of water, which is not capable of transporting solid materials. In this case, the development of bedding-plane anastomoses would have certain elements of paragenetic development. 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.

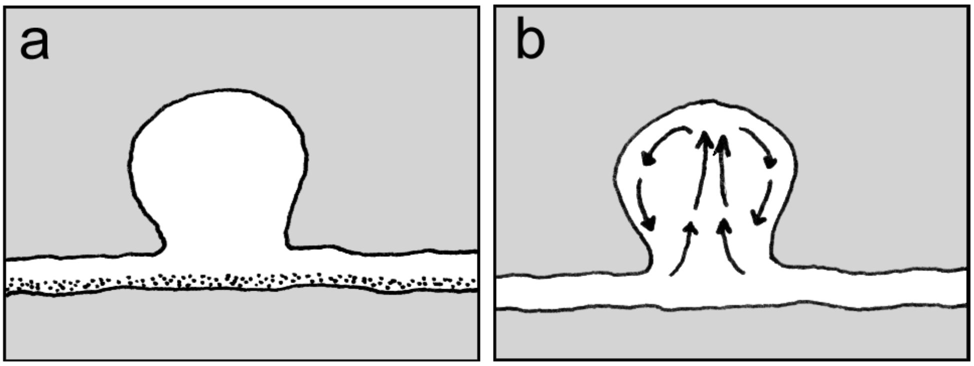

Figure 2: upward growth of anastomoses explained by: a) insoluble residue protecting the lower bed; b) natural convection of water

The most complex analysis of this karst phenomenon was given by EWERS (1966), who 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. 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 (Fig. 2b).

One possible explanation was described by LOWE (1992), although he was not referring particularly to bedding-plane anastomoses, but to general genesis of primary karst conduits. The hypothesis relies to differences in solubility of beds (due to varying contents of calcium carbonate, grain size, type of carbonate cement, etc). Since sedimentary boundaries are characterized by the presence of micritic limestone below and sparry limestone above the boundary, then "...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).

Other Types of Anastomoses

Above-sediment anastomoses are, when compared to bedding-plane anastomoses, similar in appearance, but different in origin. They are formed as a consequence of filling of cave passages (entire passages or just overhangs) 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.

Apart from bedding-plane anastomoses, WHITE (1988) also mentions joint-plane anastomoses. Existence of this type of anastomoses is in contradiction with the last of the above mentioned upward growth hypotheses (solubility differences between beds). In the areas which are to a high extent tectonically fractured, these two types of anastomoses can both be present, and majority of joint-plane anastomoses are formed in steeply dipping joints. It is interesting to notice that almost in all cases anastomoses are developed with vertical longer axis, and are not perpendicular to bedding or joint planes.

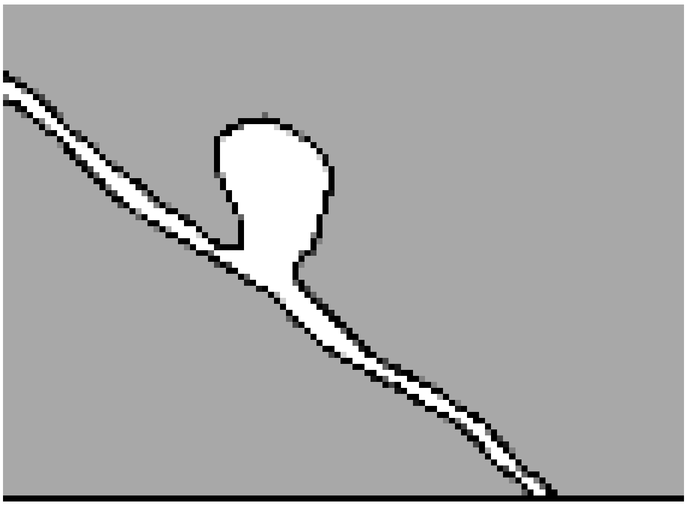

Figure 3: anastomoses in steeply dipping planes (bedding or joint)

It is usually considered that all bedding-plane anastomoses are antecedent, i.e. formed before cave passages developed. However, WHITE (1988) states that there are some evidence that in certain cases anastomoses can be younger than the cave passages in which they are visible (or formed contemporaneously), by water that penetrates into the bedding or joint planes, as a consequence of flooding of the passage (due to damming of the flow, increased hydrostatic pressure, etc).

Implications on Speleogenetic Studies and Suggestions for Further Research

If we accept that the bedding-plane anastomoses are among the earliest solutional openings in limestones, the need for their more detailed study becomes quite obvious. The cases in which anastomoses are direct reason of passage development (large enterable anastomoses which represent anastomotic maze cave passages, or collapse of several beds in sequence that occured due to formation of anastomoses and consequent disrupted stability) are not of such great importance as the understanding of the development mechanism itself.

Examination of the hypothesis on the influence of solubility differences between beds should be carried out with the help of thin sections analyses, experimental dissolution of compact samples (not powdered!), calcimetry, etc. Hypotheses on the impact of insoluble residue or natural convection of water require careful modeling and application of physics of fluids.

Besides the mechanism of development, the sequence of events is also to be researched. The cases in which anastomoses axes in inclined bedding or joint planes are perpendicular to planes have still not been reported in speleological literature (which, of course, does not mean that these cases do not exist). That would mean that formation of anastomoses took place only after the events of uplift or folding of limestones. Though, it must be expected that the different succession of events is also possible.

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