Healed speleothems: testimony of seismotectonic activity of karst areas

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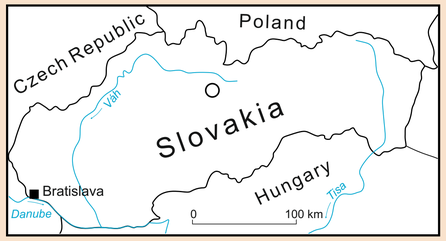
The term *healed speleothems* refers to the speleothems that were subjected to fracturing as a result of brittle deformations. The originated fractures were subsequently filled by calcite. So far, such a phenomenon has not been described in details in the literature. The studies were carried out to characterize the healed speleothems and recognize the mechanisms responsible for their formation.

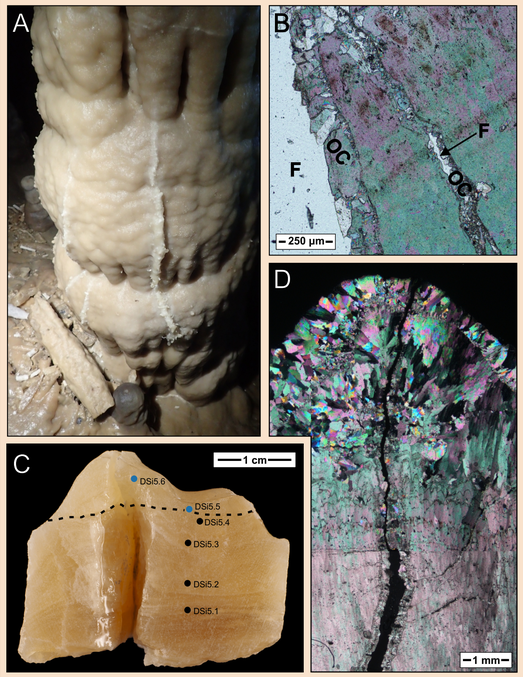
The healed speleothems have been noticed in the Čarovná passage – one of the side passages of Demänová Cave System (DSC; the Low Tatra Mts, northern Slovakia). The passage richly decorated with speleothems is developed along the normal fault with the SW-NE strike. There are numerous damaged speleothems, including fractured and subsequently healed columns, in this passage. The fractures form a polygonal pattern on the flowstone and column surfaces. The measured orientation of the fractures corresponds to the strike of the fault that guides the passage. The width of the fractures ranges from 0.02 mm to 0.4 mm.



Localization of the Demänová Cave System indicated by a black circle.

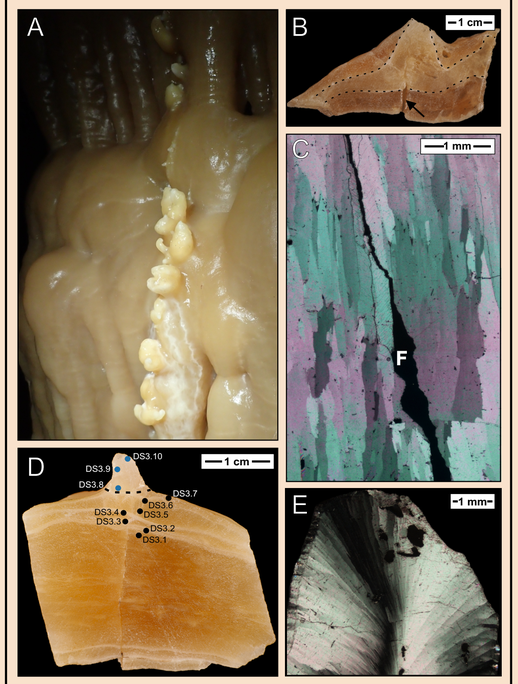
Numerous broken speleothems cover Čarovná passage floor.

Sub-vertical ridges



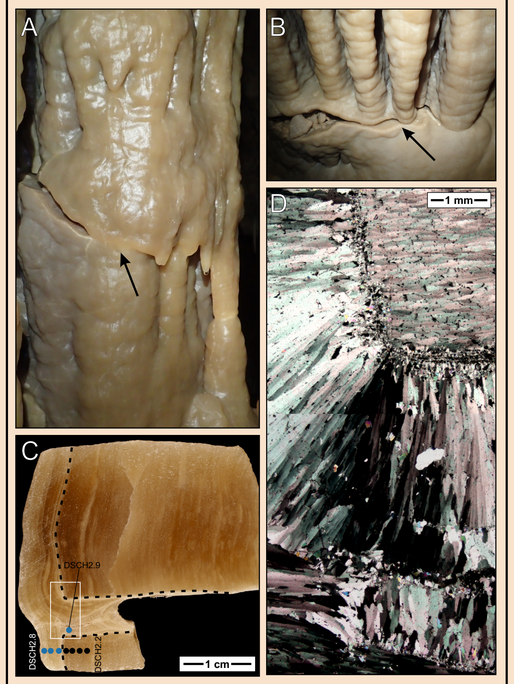
A) The crystallization of calcium carbonate that propagate within the column; **B)** the fractures (F) in the speleothem overgrown by calcite (OC); **C)** steeply inclined slopes observed in the sub-vertical ridge cross-section. Dashed line indicates the boundary between the speleothem and its healed part, dots show the $\delta^{13}C$ and $\delta^{18}O$ sampling places; **D)** the crystals arrangement in the sub-vertical ridges contrast with the homogenous development of the host speleothem.

Helictites



A) The individual massive helictites crystallized in the fracture mouth; **B)** helictite (indicated by the dashed lines) fed by the fracture (arrow) that propagates in the flowstone; **C)** fracture (F) that fed the helictite. No crystallization of calcium carbonate has been noted within the fracture; **D)** helictite and its host speleothem cross-section. Dashed line indicates the boundary between the speleothem and its healed part, while dots show the $\delta^{13}C$ and $\delta^{18}O$ sampling places; **E)** the radial-fibrous microfacies that build the helictites.

Sub-horizontal ridges



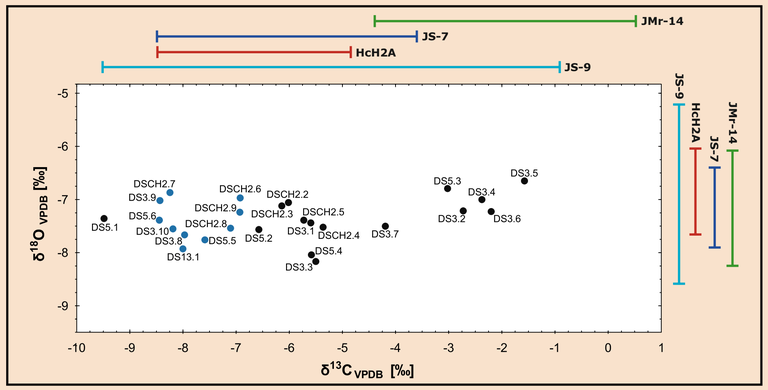
A) The crystallization of the sub-horizontal ridge within the column fracture (black arrow); **B)** notable fracture partly overgrowed by a sub-horizontal ridge; **C)** cross-section of sub-horizontal ridge, the subtle bulge formed on the upper lip of fracture' mouth. White frame indicate area presented in figure D. Dots show the $\delta^{13}C$ and $\delta^{18}O$ sampling places. The dashed line indicates the boundary between the host and healed speleothem; **D)** the sub-horizontal ridge composed mainly by the elongated columnar microfacies, note the change in crystal orientation between speleothem substratum and its healed part.

Internal water supply

External water supply

The polygonal pattern formed in the flowstone as a result of the healing process.

Polygonal pattern in a healed column.



The carbon and oxygen stable isotope composition of the host speleothems (black dots) and their healed speleothem (blue dots) in relation to the values obtained for the stalagmites collected in DCS (data compiled from: Benson et al., 2018; Hercman et al., 2020; Pawlak, 2021).

The growth of the sub-vertical ridges and helictites was controlled by the internal flow of water within the fractures, while the sub-horizontal ridges developed due to gravitational water flow down the surface of the columns. This hypothesis is supported by (i) the morphology of the healed speleothems and (ii) the orientation and widths of the fractures.

The distinct depletion of $\delta^{13}C$ values has been observed between the host and healed speleothems. The most plausible explanation of the more negative $\delta^{13}C$ of healed speleothems is a crystallization under conditions that varied from those in which their substratum were formed.

References:

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