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What is hidden in caves? Sheared flowstone as a marker for slip rates

Ivanka Mitrovic (1,2), Lukas Plan (1), Bernhard Grasemann (2), and Ivo Baron (1)

(1) Cave and Karst Group, Natural History Museum Vienna, Museumsplatz 1/10, Vienna, Austria, (2) Department for Geodynamics, Center for Earth Science, University of Vienna, Vienna, Austria (ivanka.mitrovic@univie.ac.at)

Speleothems are cave deposits, mostly consisting of calcite minerals, and they can be used to investigate tectonic activity of a region, giving that caves naturally preserve past and present conditions often difficult to observe at the surface. Flowstone is a type of speleothem, deposited out of water films along cave walls and is usually characterized by uniform crystal growth characterized by calcite c-axis perpendicular to the cave wall. Scratched flowstone, found in Hirschgruben cave, Austrian Alps, was deformed due to a strike-slip fault movement that occurred between 118 ka and ca. 9 ka, at depths of 190 m below the surface (1890 m above sea level) and low temperatures (0-5 degrees Celsius). After the deformation, a thin layer of younger flowstone coated the scratch, preserving the original slip surface. This allows us to investigate well-preserved natural examples of fault behavior and here we show its complexity.

Naturally deformed speleothems have been sheared due to activity of the SEMP (Salzach-Ennstal-Mariazell-Puchberg) fault system and present unique field evidence for active displacement along this fault. The 300 km long SEMP fault accommodated a sinistral displacement of about 60 km related to the Neogene and Quaternary lateral extrusion of the Eastern Alps towards the Pannonian Basin, coeval with north-south shortening between the Adriatic and European plates. Microstructural analysis of sheared flowstone pose evidences for changing fault behavior, including both seismic slip and aseismic creep. To investigate these mechanisms, we implemented series of high-resolution electron beam analytical techniques including scanning electron microscope, cathodoluminescence and electron backscattered diffraction. The most common structural characteristics, such as grain size reduction, mechanical twinning and the presence of crystal-plastic deformation suggest complexity of the fault.

In order to better understand this complex fault behavior, we perform friction experiments, using undeformed flowstone from the same cave to deform them in laboratory. The nature of flowstone growth, with calcite composites growing perpendicular to the wall, allows us good crystallographic control during experimental friction tests. The samples deformed in the laboratory will be analyzed using the same set of analytical techniques and compared with natural examples. This way of combining field and experimental methods help us to understand the fault's slip mechanisms and its potential to produce earthquakes.