Investigation of subrosion processes using an integrated geophysical approach

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**Motivation**

- Subrosion – leaching of soluble rocks (i.e. rock salt, anhydrites, gypsum and limestone) mostly due to groundwater
- Natural origin; sometimes enhanced by anthropogenic interference
- Sometimes subrosion processes have catastrophic consequences
- Recent, haunting examples in Germany: unexpected collapse events and associated damage caused by sinkholes in Schmalkalden and Tiefenort 2010 and Nordhausen 2016
- Knowledge about processes and therefore ability of prediction of such events insufficient
- Complexity of processes requires an integrated geophysical approach: investigation of fundamentals of structure, hydrodynamics, solution processes and mechanics as well as their interconnection
  - study multiple aspects of subrosion taking advantage of different physical properties and mechanisms

**Petrophysics**

This study investigates the complex electrical properties of carbonate rocks. The analysis takes place in combination with petrophysical, mineralogical and geochemical measurements.

**Example**: Laboratory experiments on a large variety of carbonates were conducted that cover a wide range of petrophysical parameters. The SIP-measurements showed four different types of polarization behaviour in the spectra of imaginary part of conductivity (σ''). The relationship between σ'' and the real part of surface conductivity (σ'surf) for four different types of polarization behaviour in the spectra of imaginary part of conductivity (σ'') and σ'surf for varying pore space.

**Surface Deformation**

Gravimetric and geodetic measurements are performed to monitor time-dependent, subrosion-induced characteristics, i.e., ongoing subsidence and mass movement in the subsurface caused by leaching.

**Example**: Since March 2014 precise levelling campaigns and a GPS campaign using four different gravity meters were performed in the city centre of Bad Frankenhausen (Thuringia, Germany).

**Electromagnetics**

The aim is to utilise electromagnetic methods, georadar and electrical resistivity measurements for the characterisation of karst structures, sinkholes and disintegration zones and distinguish those from the undisturbed rocks.

**Example**: In Bad Frankenhausen (Thuringia, Germany) borehole georadar constant-offset and tomography measurements have been performed.

**Seismics**

SH-wave reflection seismic is well suited to image and characterise near-surface subrosion structures and to identify unstable zones, especially in combination with P-wave reflection seismic and VSP.

**Example**: In 2010 a sinkhole of 30 m diameter and 20 m depth opened in Schmalkalden (Thuringia, Germany). In the vicinity of the backfilled sinkhole, seven shear wave reflection seismic profiles were acquired using a 120-channel landstreamer attached with horizontal geophones and an electrodynamic micro-vibrator, exciting horizontally polarized shear waves.

**Numerical Modelling**

To better understand the underground structures and subrosion processes, part of the research is to simulate the collapse mechanism and rock failure to specify the conditions in which sinkholes form.

**Example**: Failure predicted by stress in intact rocks (using the roxol code, based on latest XFEM routines):
- Failure begins in the central upper part of the cavity.
- It propagates concentrically from the top of the cavity to the Earth’s surface.
- The final fracture system builds an arch, from which blocks will probably fall out.

**Conclusion & Outlook**

Considering different perspectives:

- Investigation of structure on different scales by georadar and shear wave reflection seismic
- Temporal aspects and evolution as well as understanding of essential processes by numerical modelling, SIP perception and solution experiments and monitoring of deformation

Future Work:

- Integration of structural information, monitored deformation and knowledge about solution processes into detailed numerical models and simulation of subrosion processes
- Identification and characterisation of areas of high risk based on multiple aspects