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SH-wave reflection seismic and VSP as tools for the investigation of sinkhole areas in Germany

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Sinkholes can lead to damage of buildings and infrastructure and they can cause life-threatening situations, if they occur in urban areas. The process behind this phenomenon is called subrosion. Subrosion is the underground leaching of soluble rocks, e.g. anhydrite and gypsum, due to the contact with ground- and meteoric water. Depending on the leached material, and especially the dissolution rate, different kinds of subrosion structures evolve in the subsurface. The two end members are collapse and depression structures. For a better understanding of the subrosion processes a detailed characterization of the resulting structures is necessary.

In Germany sinkholes are a problem in many areas. In northern Germany salt and in central and southern Germany sulfate and carbonate deposits are affected by subrosion. The study areas described here are located in Thuringia in central Germany and the underground is characterized by soluble Permian deposits. The occurrence of 20 to 50 sinkholes is reported per year. Two regions, Bad Frankenhausen and Schmalkalden, are investigated, showing a leaning church tower and a sinkhole of 30 m diameter and 20 m depth, respectively.

In Bad Frankenhausen four P-wave and 16 SH-wave reflection seismic profiles were carried out, supplemented by three zero-offset VSPs. In Schmalkalden five SH-wave reflection seismic profiles and one zero-offset VSP were acquired.

The 2-D seismic sections, in particular the SH-wave profiles, showed known and unknown near-surface faults in the vicinity of sinkholes and depressions. For imaging the near-surface (< 100 m depth) high-resolution SH-waves are advantageous in order to detect subrosion structures at different stages. The reflection patterns of the 2-D seismic sections indicate a heterogeneous underground with lateral and vertical variations in forms of discontinuous reflectors, depressions, small-scale fractures and near-surface faults. Probably the faults and fractures serve as pathways for groundwater, forming cavities due to the increase in rock permeability. Besides these structures, anomalies of the seismic velocities and the attenuation of seismic waves are visible, especially in the SH-wave profiles. Low velocities < 200 m/s and high attenuation may indicate areas affected by subrosion. Other parameters characterizing the underground stability are the shear modulus, derived from shear-wave interval velocities and density, and the Vp-Vs ratio. The 1-D and the 2-D data revealed zones of low shear modulus < 100 MPa and high Vp-Vs ratios > 2,5, probably indicating unstable areas due to subrosion.
We conclude, that SH-wave reflection seismic offer an important tool for the imaging and characterization of near-surface subrosion structures and the identification of unstable zones, especially in combination with P-wave reflection seismic and zero-offset VSP with P- and S-waves. Presumably there is a connection between the presence of large fluid pathways, like faults, and the occurrence of widespread subrosion.