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# Geophysical characterization of shallow karst

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In seismic exploration, karstified areas are known to be notoriously difficult ground for subsurface imaging. Apart from problems of effective source and receiver coupling to the ground, karst can cause strong near-surface scattering effects, which interfere with the signals of interest. A detailed understanding of the geometry and geophysical properties of karstified near-surface layers and the impact of karst structures on seismic-wave propagation are therefore critical to mitigate imaging problems related to karst. Most geophysical investigations of karst phenomena focus on the most prominent karst features such as sinkholes (dolines) and caves because these are spectacular and/or may represent hazards. However, understanding karst evolution and the interaction of weathering, lithology, and tectonic history of a karstified area requires a thorough understanding of the entire near-surface zone between the surface and the intact carbonate rock at depth.

Motivated by the need to study karstification at two field locations and to understand its impact on seismic wave propagation at these sites, we conducted a multi-method geophysical field campaign in the Swiss Jura Mountains (Western Switzerland). The area is covered by a thin soil layer (thickness generally < 1m), which is underlain by karstified Malm limestones. We conducted single-component and multi-component seismic reflection and refraction experiments to image the subsurface at scales of 10's to 100's of meters. In addition, we acquired electrical resistivity tomography (ERT) data to resolve resistivity variations in the topmost several 10's of meters. The ERT data were complemented at the meter to 10-meter scale by depth soundings with two different electromagnetic systems (EM31 and EM34). Finally, ground-penetrating radar (GPR) measurements were conducted to image the uppermost few meters of the subsurface in great detail. Overall, data of high quality were obtained with all methods.

The final P-wave velocity tomograms and resistivity images exhibit significant parameter variations in both the horizontal and vertical directions; the P-wave tomograms, for example, indicate velocity changes from a few hundred to a few thousand m/s over short distances for carbonate rocks close to the surface. These variations in physical parameters are likely caused by changes in the lithology and in the degree of karstification, with the latter seeming to be the dominating factor. With respect to the karst impact on seismic wave propagation, we observe pronounced lateral changes in the characteristics of the densely sampled wavefield. For example, distinct changes in the surface-wavetrain characteristics can be related to strong lateral seismic-velocity changes observed in the tomograms. ERT-derived resistivity models show sub-horizontal layering at the 10-meter scale with an orientation (dip, strike) that agrees with the geological model of the area. The complementary EM soundings largely concur with the shallow ERT models, but ERT and EM results show only moderate correlation with the P-wave tomograms indicating that seismic and electric/electromagnetic properties of the karstified carbonates are only weakly linked. The GPR images show shallowly dipping reflectors with dips that are in overall agreement with observed dips of the surface-exposed bedding.