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The role of lithological contrasts in the formation of sinkholes: a Distinct Element Method modelling perspective

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Sinkhole formation is a geological phenomenon resulting from dissolution and subrosion of rocks or sediments at depth, where large secondary pore space and cavities may develop, and from the eventual subsidence of the overburden. Although sinkholes may develop slowly as a natural process, their formation is often intensified by human activities. For instance, sinkhole hazard has intensified at the Dead Sea shoreline in the Middle East since the beginning of the recession of the Dead Sea level. Another example concerns sinkhole formation induced by solution mining of salt rock in the Lorraine district, France.

Signs of precursors to collapse sinkholes have sometimes been indicated by monitoring studies, but are not well understood in terms of quantitative models. Here we report on a general, simplified approach to simulating sinkhole formation by using 2D Distinct Element Method (PFC2D) models comprising elastically bonded particles. The presence of bonds leads to elastic rock deformation under loading conditions and bond breakage may result in spontaneous formation of faults and cracks. Using different rheological parameters like Young's modulus, density, cohesion and friction coefficients, this method is able to simulate realistic rock layering contrasts. The dissolution or subrosion process leading to the formation of underground cavities is simulated via simple incremental particle deletion, whereby an arbitrary dissolution rate can be determined. Model structures preceding a sinkhole collapse, as well as precursory changes in density or porosity, are explicitly simulated and may be linked to measured geophysical parameters such as microseismicity, seismic velocity and electric conductivity.

As well as examining precursory phenomena, we study the effect of lithological contrasts on (1) the geometry of sinkholes (diameter to depth ratio) and (2) the onset of collapse. Beside the formulation of general relations, we compare our simulations to well documented case studies. As a reference case, the geophysically monitored sinkhole collapse of Cerville-Buissoncourt in Lorraine in France is used. There, specifically, the role of a stiff dolomitic layer is investigated for the stability of the underground cavern and used for calibration.