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PROFILING OF SINKHOLES IN THE METROPOLITAN REGION OF HAMBURG AND LÜNEBURG WITH GROUND PENETRATING RADAR (GPR)

N. Buurman, C.-D. Reuther

Department of Geosciences, University of Hamburg

The sub-surface geology of Northern Germany is characterized by numerous deposits of Permian salt. During Triassic and the Early Jurassic, E-W extension and deposition of clastic sediments initiated the uprising of underlying Zechstein evaporites from about 5000 m depth up to the surface. In the Late Cretaceous to Lower Tertiary the latest phase of salt tectonic was activated, indicated by salt diapirism and horizontal shortening of the salt domes. As a consequence of diapir emplacement Mesozoic rocks were steeply to sub vertically displaced and deformed around the salt dome margins. Tertiary and Quaternary deposits, varying in depth and thickness, cover the caprock evaporites like gypsum, anhydrite and karst.

The humid climate of Northern Germany supports dissolution processes of evaporites by ground water formation. According to the salt table (Lüneburg: -20 to -40 m; Hamburg Othmarschen-Langenfelde: $\sim$0 to -250 m) cavity grow is the consequence of subrosion in the subsurface. Cohesive soil that is clay-bearing or indurate can bridge over a void, but subsequent dissolution makes roof failure inevitable. As a result of the collapse, subsidence structures such as circular and conical features occur at the surface. The mode of subsidence of sinkholes depends on the time of their formation: There are dropout sinkholes caused by ground failures and sudden collapses, or the suffosion sinkholes where the ground subsides slowly. Instantaneous or rapid surface failure of the dropout sinkhole is the main geohazard in terrains of soil-covered evaporites and represents a strong potential georisk especially in metropolitan regions with a well developed infrastructure and a high concentration of built-up areas. In contrast the suffosion sinkhole develops by particulate tapping of a non-cohesive, purely sand soil into a narrow underlying fissure, matched by slumping and subsidence of the soil profile. The georisks of this creeping soil movements are moderate to strong, depending on the mass deficiency.

During the last two centuries the metropolitan region of Hamburg has been affected by the development of about 40 sinkholes above the SW-margin of the Othmarschen-Langenfelde diapir (OLD). Most of them are small size suffosion type sinkholes located in a wide NS-striking basin, the “Bahrenfelder Senke”. For the detection and evaluation of the subsurface dimensions of buried depressions and raveling soil pipes we use the GPR. Although the slowly creeping soil actually represent just a moderate georisk, surrounding facades of buildings, roadbeds and pavements show visible damages. GPR sections reveal that buildings and basements are constructed above buried subsidence edges, slide planes and areas of raveling soil. The GPR profiles also document sediment infillings of the sinkhole showing multiple deformation that postulate a sequence of subsidence collapses and subsequent backfilling at the same location by ongoing subrosion in the deeper underground. A second NS-orientated basin above the western margin of the OLD is called “Flottbeker Senke”. Morphological steps characterize its steep north-western rim that dips down to the throat of a dropout type sinkhole. Three sudden collapse events accompanied by local earthquakes (1928, 1963, 2000) are documented in the last century. GPR data from outside of the perimeter of the collapse center show the real extension of the subsidence area by means of buried subsidence edges. Recurring settlement damages on buildings confirm ongoing subsidence and soil movements in times between sudden ground surface collapse events as well.

Another case study from the western part of the city of Lüneburg exhibits serious impacts on the local infrastructure and residential zones. Of special interest is a fast subsiding suffosion sinkhole located at the contact between Triassic rocks and the northern exterior of the Lüneburg salt diapir. Between 2002 and 2004 active subsidence reached about 20 cm/year, starting with a steep-sided collapse pipe of about 90 cm in diameter. Ongoing subsidence of ground surface developed a morphological funnel with a larger diameter of about 30 to 50 m. As a result demolished streets and buildings appear, basements sunk below the ground water level, sewer pipes and gas pipes broke off, and one house had to be evacuated until now. Detailed 3D-GPR mapping of subsidence edges down to 10 m exhibited a structural width of the funnel with more then 90 m in diameter. In zones with high subsidence rates and significant mass deficiency GPR-mapping allows monitoring of the growth of the endangered zone in the subsurface.

With high-resolution ground-penetrating-radar profiling down to a depth of about 10 to 15 m we are able to detected subsidence edges as well as the geometry and the extension of subsidence affected areas. Combined with additional test borings, fossil soils, and sediment determinations, the radar facies can be verified. The knowledge of the structural style of underground deformation helps us to define endangered zone and to estimate potential georisks in order to prevent serious damages on buildings, infrastructure and human beings.

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