Introduction

Many natural hazards are endangering the safety of humans and their possessions, among them are sinkholes. Those are depression or collapse structures caused by subrosion processes and they occur in a great range of geological formations. Sinkholes are a considerably threat to the health of individuals and can cause severe economic loss, due to their generally abrupt onset. Usually, sinkholes are linked to heterogeneities in the soluble sediments, like layer boundaries or fissures and to fluctuations of the groundwater surface.

A deeper knowledge of subrosion processes including sinkhole genesis is important to develop an early warning system for sinkhole formation. To achieve this goal the joint project SIMULTAN studied sinkholes and their precursors as well as the effects in their vicinity, in order to develop sensors and multi-scale monitoring methods (e.g. Kaufmann et al. 2018, Kersten et al. 2019). As part of this project, we examined the solution process of different materials as well as the accompanying processes and their relation to hydrologic and geohydraulic constraints from a petrophysical viewpoint. Our main objective are measurements of the complex, frequency dependent electrical conductivity of materials in karst areas. As a case study, field measurements were conducted in the German rural municipality Münsterdorf where there are ongoing recurring sinkhole appearances, as well as laboratory measurements (Mai et al. 2018).

Theory

Figure 1 shows the general concept of our measurements. Because sinkholes occur when a soluble substance is dissolved and the overlying material fills the developed cavity, the area of main interest is the contact zone between the soluble rock and the overlying rock. To study this area we used monitoring measurement of the spectral induced polarisation (SIP).

SIP is used to determine the complex electrical conductivity of the subsurface. Like with ordinary geoelectrical measurements a current is injected into the subsurface and the electric field is measured with of distributed voltage dipoles. Because the electrolytic conductivity by way of charge carriers in the pore space fluid is dominant in unconsolidated sediments, a current application and the resulting electrical field will lead to an orientated movement of the charge carriers within the pore water. Due to this effect, the charged particles will accumulate at pore necks, which affects the mobility of the charge carriers and thus the conductivity. This increased concentration of equal charge carriers induces an electric counter field and leads to measurable polarisation effects. This leads to a frequency dependent phase shift, which is measured during a SIP survey (Olhoeft 1979, Schön 2015).

As a result of the special characteristics of SIP measurements they are highly sensitive to changes in pore water composition, even if there is no change in resistance (Börner et al. 1993). We used this quality to monitor an area of high sinkhole probability during the time span from July 2016 to March 2019. The aim was to see if a change in the concentration or type of ions either in the soluble rock itself or in the overlying material due to solution processes could be monitored over time.
Field Measurements

The location for the measurements is the municipality Münsterdorf located about 50 km north of Hamburg in Germany. For over 15 years, there have been recurring sinkhole occurrences in the area around the local sports field approximately every other year (see for example figure 2). These sinkholes are two meters wide and deep in average and seem to occur in a limited area passing from southwest to northeast.

*Figure 3 Outline of the two drill holes (DH) and the electrode array installed in Münsterdorf.*

The North German basin has many salt deposits, a lot of them intruded into the overlying rocks in the form of salt diapirs. The so-called Krempe-Lägerdorf diapir is located in the subsurface of Münsterdorf. With the rise of the salt, the overlying strata was in some instances disrupted but also partly lifted closer to the surface. This happened with the chalk of the upper Cretaceous so it is found approximately 20 meters below the surface in the study area (Gebregziabher-Gared 2011). The limestone is a soluble material and the transition zone between it and the overlying glaciofluvial sand inter-bedded with till is our area of main interest.

Because of the high number of sinkhole occurrences and good accessibility of the Münsterdorf area, a number of studies have been conducted in the past, e.g. Harland (2010), Gebregziabher-Gared (2011), Kirsch et al. (2015) and Kaufmann et al. (2018). Most of these works focus on the detection of cavities or disturbances in the layering in the subsurface to locate possible areas for forthcoming new sinkholes. Our objective was to study traceability of solution processes already in the early stages, even before cavities haven been formed.

To monitor karstification and subrosion processes on a field scale, a stationary measuring system was installed in Münsterdorf. It consists of a measuring array in two approximately 25 m deep boreholes located five meters apart, each measuring strand equipped with electrodes placed every meter (figure 3). SIP tomographic measurements have been conducted regularly with many different configurations, which were jointly analyzed.

Results

The measured data was evaluated with the open access software pybert (Rücker et al. 2017). After the installation of the measuring array in the drill holes, the disturbance of the subsurface due to the drilling process was observable for approximately 3 month. After this settlement period, the analysis
of the measurement data showed constant result with minimal variation, mainly in the areas close to the surface. Figures 4 and 5 show the results for the electrical resistivity and phase shift respectively over a period of a little bit over a year. It can be observed, that the values for the electrical resistivity match the lithological information obtained during the drilling process quite well. The till layer between 12 and 14 meters is represented by low resistivity data and the overlaying sand shows higher values of complex electrical resistivity. On closer inspection of our area of main interest at the transition zone between the overlying quaternary loose sediments to the chalk layer the results are nearly constant over time. Only the measurements in January 2018 and August 2018 differ from the other campaigns.

**Figure 4** Electrical resistivity results of measurements between July 2017 and August 2018 next to the lithology of the two drill holes (obtained from the flush drilling).

**Figure 5** Phase shift results of measurements between July 2017 and August 2018 next to the lithology of the two drill holes (obtained from the flush drilling).

Looking at the plots for the phase shift, we note similar results. The values just show minimal variation primarily in the meteorologically influenced layers close to the surface. The only exception from this is the plot for January 2018. There we see lower phase shift values above the chalk boundary in comparison to the previous and following months. In August 2018, there is no change in phase shift results, contradictory to the outcome of the resistivity measurements.

It is to be noted, that just a few days after the measurements conducted in January 2018, a sinkhole was discovered approximately 20 meters away from the measuring site. It can be assumed, that this
incident had an impact on our measurements, since this was the only time changes in the measuring results have been observed.

Conclusions

Our results indicate solution processes occurring at the transition zone between the subterranean chalk and quaternary loose sediments. The main Advantage of SIP measurements in comparison to electrical resistivity tomography is the additional measurement of the phase shift. Our results show that for the observation of subrosion processes it is beneficial to have these values as well. This is apparent due to the fact that the anomaly in the resistivity values for January 2018, a time known to coincide with a sinkhole occurrence, is not very prominent, whereas the results for the phase shift at that time show significant changes. On the other hand, a more significant anomaly in the electrical resistivity in August 2018 cannot be depicted in the phase shift values. There was no apparent sinkhole appearance at that time. The phase shift values seem to be an important indicator for solution processes in the subsurface.

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References


