GEOPHYSICAL AND GEOMECHANICAL MEASUREMENTS AS MEANS FOR THE MONITORING OF MINING INDUCED FRACTURING PROCESSES AT POTASH AND ROCK SALT MINES

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ABSTRACT

We present the necessity and the benefit of comprehensive monitoring of active and abandoned salt mines. The effects of both tectonics and mining frequently lead to consequences such as roof falls and mine collapses. We present three examples of salt mines in various states of stabilty, with partially significant subsidence rates at the surface in densely populated areas. We identify weakened structures in the mines by comprehensive monitoring programs, involving geomechanical, geophysical and geodetic measurements. The corresponding mines fields are then stabilized by backfilling selected cavities. We present the course of the restoration activities and the positive effect on mine stability as observed by the monitoring.
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Introduction - Why do we need monitoring?

Cavity volumes in potash and rocksalt mines often amount to more than 10 million m³ per mining field and are located within the Zechstein formation in depth ranges between a few hundred meters and more than 1000 meters. The salt formations are most often covered by triasic sediments including water bearing horizons. The salt deposits are separated from the water bearing horizons by protective layers, usually consisting of clay or materials containing clay. The hydrogeological hazard of water entering a mine depends on the individual properties and the thickness of the protective layer. Waters entering the mine via conduits, either newly created or activated due to straining processes, catalyse a scenario that affects the ground surface significantly. A possible consequence of the access of unsaturated fluids can be the loss of stability of the mine structure due to subrosion processes. The magnitude of subsequent rupturing processes, in some cases progressing to the surface, mainly depends on the physical properties of the salt. Subsidence of the ground surface was observed as a consequence of convergence of cavities within the mine affecting buildings, transportation infrastructure and bodies of water. Rock bursts and similar seismic events represent dynamic effects at surface level. The resulting consequences, possibly affecting sensitive buildings, can compromize public safety considerably. To protect the ground surface, the status of the mining cavities must be monitored and effective concepts for the maintenance of the mine have to be applied. These are usually derived from the long term behaviour, including the release of energy, of the salt rocks.

Geotechnical monitoring and maintenance

To assess and characterize processes relevant to damages and their effects on the mine structure, in the overburden and at the ground surface, Kali-Umwelttechnik GmbH, Sondershausen (*K-UTEC*) applies the following monitoring methods with very good success (also with regard to economic aspects).

- *In situ* assessment of the status and/or automated remote monitoring
- Repeated geomechanical measurements within the mine (hydrofracturing, measurements of convergence of cavities and contour movement)
- Seismic monitoring of the mine field and its vincinity (design, manufacture and configuration of the monitoring systems; and installation, calibration, maintenance and operation thereof).
- Subsidence measurements and leveling at the surface

Efficient monitoring comprises the comprehensive and accurate modelling of the status of the mine in terms of mining, geomechanics and geology. In case of brine influx hydrological and geochemical models must also be considered. This serves to analyse the sensitivity of those processes relevant to possible mining induced damages with respect to the modelled parameters, and with special consideration of the ground surface and the immediate vincinity of the mine field.

Potentially dangerous situations ideally are avoided during active mining. This is realized by the design of salt extraction and by the dimensioning of cavities, pillars and thicknesses of the protective layers. Moreover, the deformations are monitored and the mining cavities are backfilled to avoid stress accumulation. After the active mining phase is completed, the mine has to be maintained in order to mitigate damage to the ground surface. This typically involves the backfilling of especially endangered mine sections with mining-related solid backfilling materials, non-mining-related solid backfilling materials and suspensions, and/or the flooding of the mining cavities with appropriate fluids.

Monitoring of deformation processes and the effects of backfilling activities

The first example is a part of the mine „Glückauf" in Sondershausen, the oldest active potash and rocksalt mine in the world. In this mine Hart-Salz, carnallite and mixtures thereof have been produced since 1898. The central part of the mine field covers an area of 6x10 km², partially beneath settlements of the town of Sondershausen. The production depths vary between 600 m and 1000 m beneath the ground surface. Until 1991 a total amount of 110 million tons mine-run salt was extracted with a maximum annual production of 2.5 million tons of salt. The production was stopped in 1991 and the mine was stabilized by backfilling the existing cavities with non-mining-related waste materials.

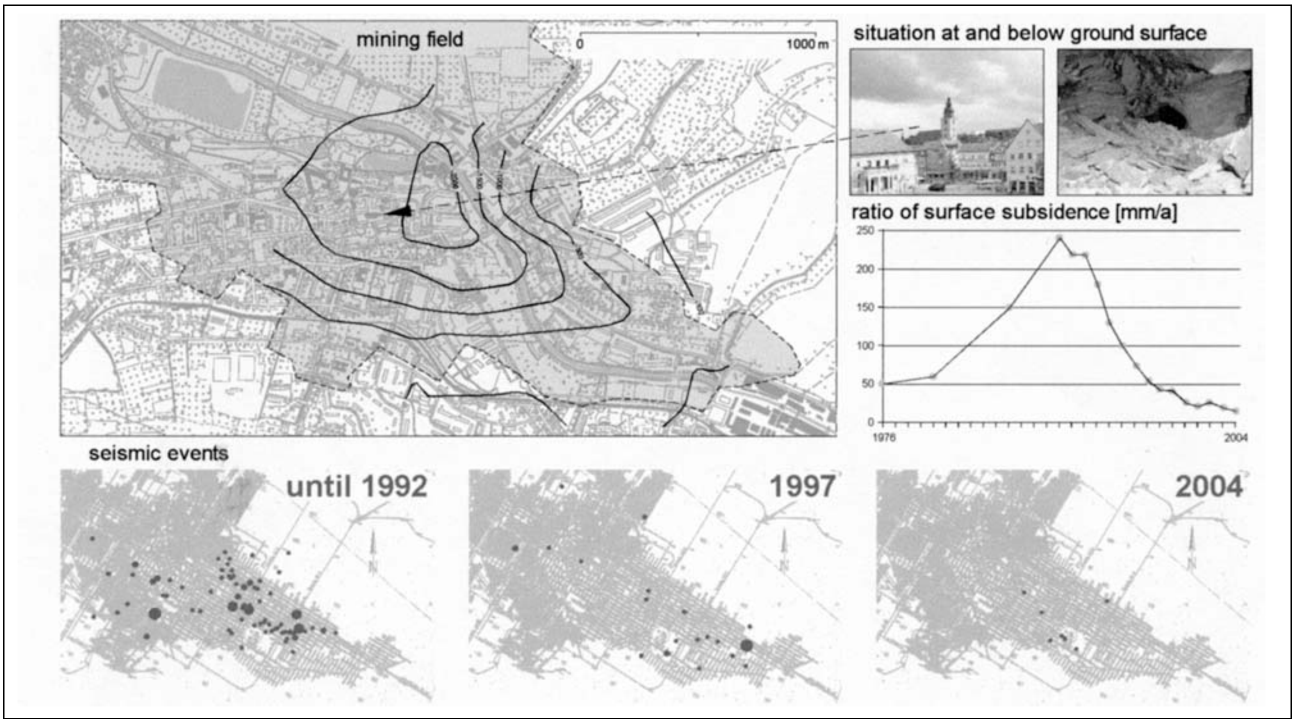

Figure 1: Location of the backfilling beneath the town of Sondershausen. Subsidence rates and seismic events are also indicated.

After the production was terminated in 1991, critical deformation and instabilities occurred in a mine field located directly beneath the town of Sondershausen (pop. 25,000). The subsidence rates, determined at the surface, ammounted to up to 25 cm per year and were accompanied by seismic events with magnitudes up to M_L=1.8. From 1991 to 1997 the corresponding part of the mine was exclusively backfilled with rocksalt that was excavated for that purpose from a different part of the mine. After the backfilling had been finished in 1997 the number and the magnitude of seismic events that were observed in that particular mine field gradually decreased, so that presently merely very weak seismic activity is recorded. The development of the observed seismicity in the years 1992, 1994 and 2004 is shown in the lower section of Figure 1.

The backfilling was accompanied by *in situ* geomechanical measurements, including hydraulic fracturing, convergence and extension measurements at pillars. These measurements were performed by *K-UTEC* using proprietory measurement devices and sensors (see example in Figure 2). As an example of a pillar in the center of an extraction field Figure 2 depicts the loading status at different times. The pillar's capabilty to act as a supporting element is clearly reduced over time, which is due to internal fracturing and deformation processes. This leads to large scale changes of the stress distribution and subsidence of the hanging wall or of the ground surface.

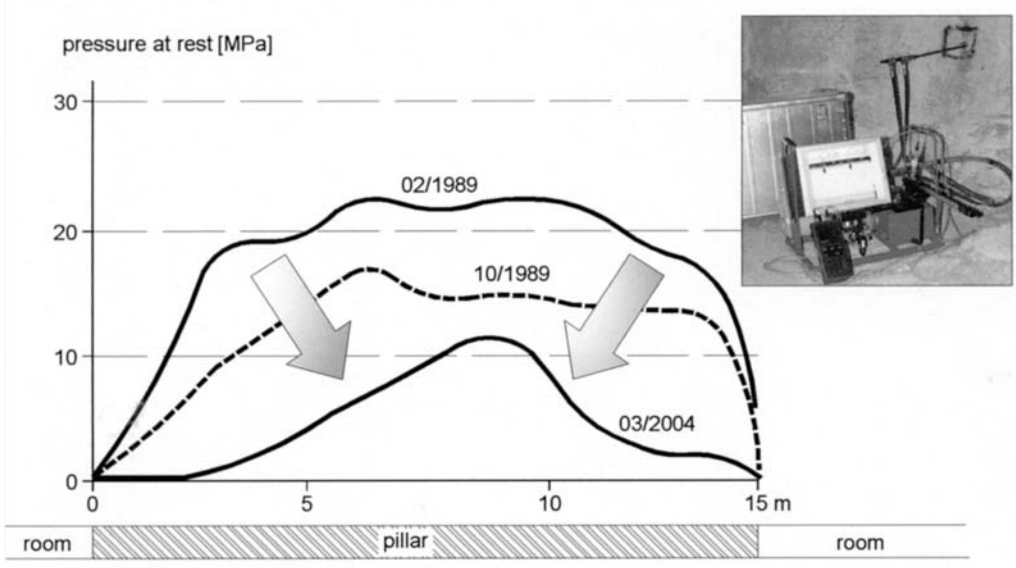

Figure 2: Decreasing pressure at rest within a pillar in the center of a mining field in an advanced state of collapse for different times.

The subsidence rates constantly decreased after the start of the backfilling activities in 1992. Since approximately 1994 the backfilling has been showing the desired large scale effects. Figure 1 contains a diagram of the subsidence rates at ground surface versus the history of the backfilling.

This example shows that major negative effects on the town of Sondershausen, such as strong seismicity and subsidence, were indeed prevented due to timely and effective application of the backfilling techniques. An important prerequisite for the optimized application of backfilling is the accompanying monitoring as provided by *K-UTEC*.

Monitoring of mine flooding

The second example describes the monitoring measures in a sensitive part of a mine that is in the process of flooding. Since carnallitite, an easily soluble salt mineral, was extracted in this particular part of the mine, this area had to be flooded using a special protective fluid (a $MgCl_2$ saturated solution) to avoid geochemical alterations and therefore weakening of the mine field. The flooding is monitored by a system of 5 pore pressure sensors and several gauges for the solution level. This serves to determine the brine density. The equipment also includes data loggers and data transmission. One of the pore pressure sensors was designed to be buoyant, so that the density near the surface of the solution can be surveyed. The other sensors are mounted at the bottom of the mine cavities to observe the integral density of the overlying solution. To improve the seismic monitoring of this mine field, the existing system was amended by an additional seismometer, installed in a borhole and sealed against brine influx.

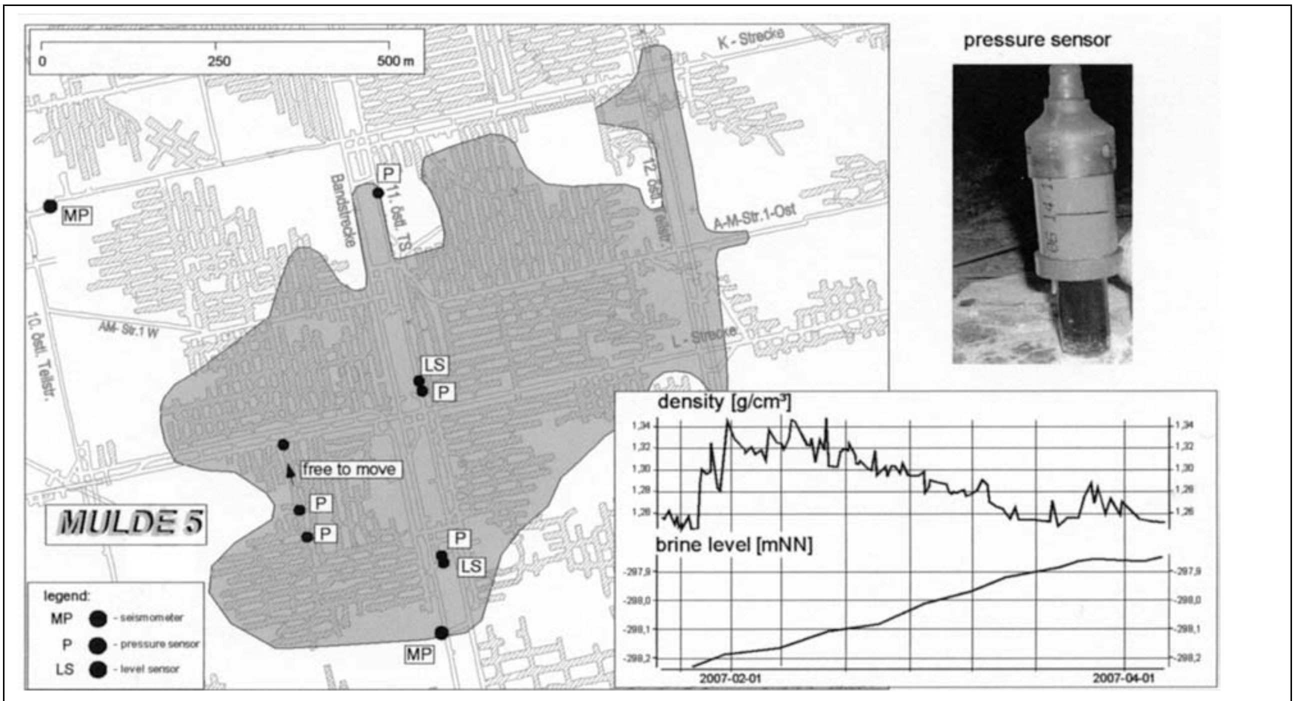

Figure 3: Mine layout of the monitored area, the installed equipment and the observed densities. In the upper right corner a pressure sensor adapted to saline environments is shown.

The harsh conditions in saline environments and the often large distances over which the data have to be transmitted demand specialized equipment. *K-UTEC* possesses the expertise in, and experience with, the design, installation and maintenance of different types of sensors and networks, especially adapted for use in saline environments. These adaptations include different ways of protecting instruments against water, brine and different solutions. An example of a modified pressure sensor is presented in Figure 3. It also contains the layout of the monitoring area and a chart presenting the development of the recorded density measurements and the rise of the brine level.

Monitoring of solution levels in a potash mine

As a third example we present a monitoring system for the solution levels in the former potash mine of Brefeld. The Brefeld mine has been abandoned for more than 60 years and is located on the south-west flank of the Stassfurt salt formation, about 30 km south-west of Magdeburg, Germany. Since the mining field extends to the village of Tarthun, the monitoring has to satisfy stringent requirements with respect to possible mining induced damages.

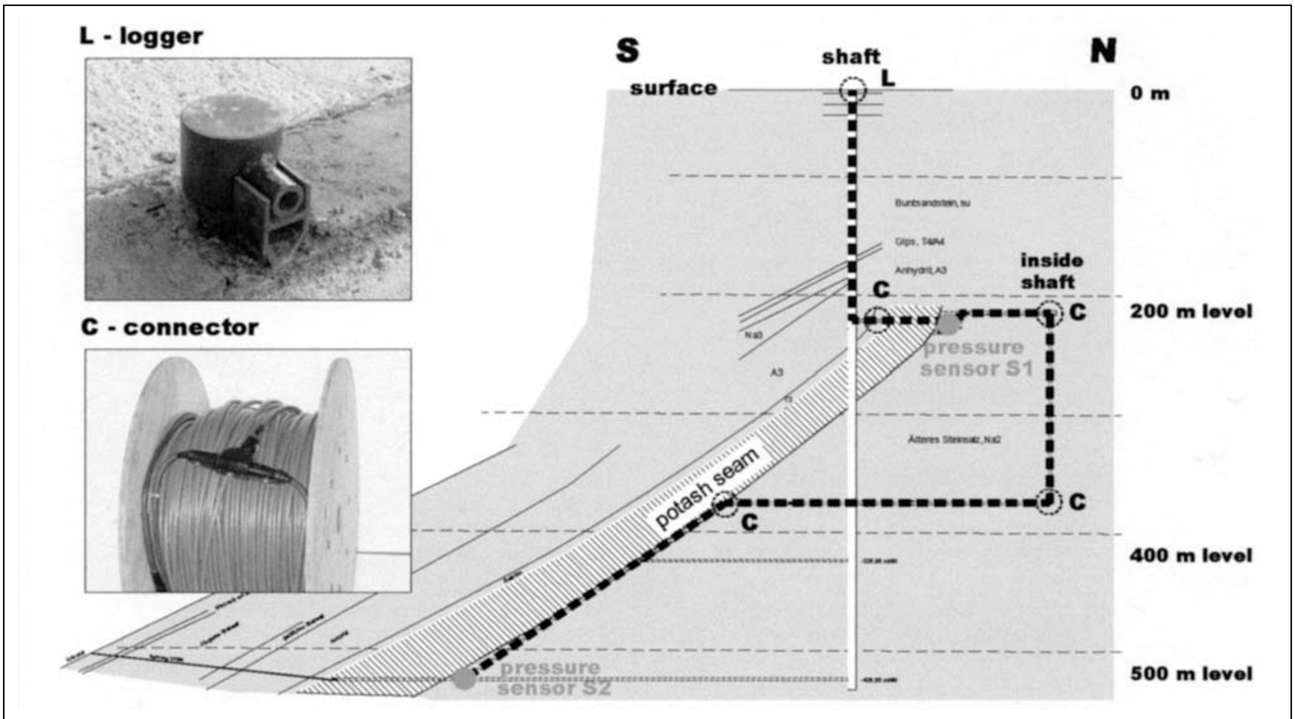

Figure 4: Cross section of the Brefeld mine showing the sensor locations, the pressure gauges, the cable connectors (C) and the data logger at the head of the shaft (L).

To extend the intervals between inspections in 2005 and 2006 an *in situ* study of all processes and parameters that are relevant for a well founded and predictive intermediate term safety analysis was performed by *K-UTEC*. In addition to that, a solution level monitoring system was installed consisting of sensor complexes installed at two key locations. These recorded the levels of existing brine reservoirs in 200 m and 500 m depth. The data are automatically recorded by a data logger with vandalism proof protective housing which was installed at the shaft cover. The installed cable was retentive, so that no additional support was necessary for the installation in the shaft. The connectors between the cables were realized using solution resistant resin covers. The sensors for the monitoring of the solution level are also modified to withstand saline environments and are based on pressure measurements using a robust and reliable string method. Pressures can be recorded in different ranges between 0.7 and 20 bars, depending on the application. The operational reliability is realized by redundant installation of two identical sensors at each location.

Summary and prospects

The monitoring activities presented in this paper provide adequate means to detect possible mining induced hazard in an early stage and ensure public safety in mining regions. Moreover they allow predictions of mining induced effects on the surface with respect to seismic events, surface movements and large scale fracturing processes. The surveillance permits rapid and effective response while the restoration activities can be tailored to the individual problem. This allows the optimization of time and effort, and ensures maximum protection at the ground surface.

Another application of the sensor configurations presented above is the monitoring of mines with limited or no accessibility. This mainly refers to flooded mines, where it allows the cost effective identification of the main processes and the corresponding derivation of appropriate and cost efficient counter measures. In addition to that, the derived data can also serve to verify numerical calculations of the processes within the mine. After the most relevant processes are identified, the area at the ground surface is subdivided into different hazard zones, with respect to the effects of processes within the mine, e.g. collapse, major subsidence and seismic events. Moreover, an alerting plan is set up which is directly linked to the seismic monitoring system, so that the safety at the ground surface is optimized.