

**Seismic monitoring of former potash mines in the south-hercynian mountains  
- Development of technology and activity**

Salt Production

**Keywords** potash, seismic monitoring, mining, risk assessment, mine safety,  
geotechnical monitoring**Abstract**

Since the end of the 19<sup>th</sup> century the exploration, mining and processing of potash are a major part of the economy in the south-hercynian area. In particular, the five large potash mines Bischofferode, Bleicherode, Sollstedt, Volkenroda and Glückauf Sondershausen, which remained in production after the Second World War, partly continued the potash mining until the end of the 20<sup>th</sup> century. After the discontinuation of mining and production of potash the trench shoring works as well as the backfilling operations were realized by private companies. These works are not completed yet within the mentioned potash mines. As a result of the predominantly specific petrophysics and rock mechanics of the mines problems with contour fracturing and rock burst prevailed (Figure 1). In order to increase the safety and productivity of the mines monitoring networks were introduced around the 1980s for a systematic recording of convergence, lateral strain of pillars and seismic activity. Consequently, a complex seismic and geotechnical monitoring provides an opportunity for a reliable assessment of potentially hazard conditions of stability of galleries and voids of the mine or several working districts as well as an accurate regulation of subsequent mine restoration steps to minimize potential danger. For decades the monitoring is an essential part of the mining activity in the south-hercynian potash mining region with a successful practical application during the mining process, the backfilling and sealing operations as well as the post-closure phase. Based on the monitoring, we are able to estimate states of destabilization as well as the hence resulting effects of stress and demands on the surface or the mine caverns. Consequently it is feasible to initiate suitable steps for safety at the right time and to execute them in a systematic order of precedence. Within the post-closure phase the seismic monitoring enables the prove of a long-term evidence in safety for the mine and the public. The key advantage of this method is the ability to be applied over a long period without even entering or surveying the relevant area. In this paper the development of the monitoring equipment as well as the practical use based on selected examples and therefore the progress of the seismicity within two south-hercynian mines is described.

## Introduction

In 1896 the exploration, mining and procession of potash salts in the south-hercynian mountains started. In particular, the five large potash mines Bischofferode, Bleicherode, Sollstedt, Volkenroda and Glückauf Sondershausen, which remained in production after World War II, partly continued the potash mining until 1992. After the discontinuation of mining and production of potash the trench shoring works as well as the backfilling operations were realized by private companies. These works are not completed yet within the mentioned potash mines. As a result of the predominantly specific petrophysics and rock mechanics of the mines problems with contour fracturing and rock burst prevailed (Figure 1). In order to increase the safety and productivity of the mines monitoring networks were introduced around the 1980's for a systematic recording of convergence, lateral strain of pillars and seismic activity.



Figure 1: Examples of potential damage due to rock pressure and contour fracturing in underground potash mining

From the 17 seismic monitoring systems, K-UTEC AG has developed and is operating in Germany and Europe four are installed within the south-hercynian area in the mines Bischofferode, Bleicherode/Sollstedt, Volkenroda and Glückauf Sondershausen. They are partly operating since the 1980's. The former potash company "Südharz" established these seismic monitoring systems to control rock fracturing up to a magnitude of  $M_L = 3.3$  which were partly connected to blastings within the Carnallitite-mining areas. Consequently, a long-term complex seismic and geotechnical monitoring provides an opportunity for a reliable assessment of potentially hazard conditions of stability of galleries and voids of the mine or several working districts as well as an accurate regulation of subsequent mine restoration steps to minimize potential danger. For decades the monitoring is an essential part of the mining activity in the south-hercynian potash mining region with a successful practical application during the mining process, the backfilling and sealing operations as well as the post-closure phase. Based on the monitoring, we are able to estimate states of destabilization as well as the hence resulting effects of stress and demands on the surface or the mine caverns. Consequently it is feasible to initiate suitable steps for safety at the right time and to execute them in a systematic order of precedence. Within the post-closure phase the seismic monitoring enables to prove the long-term evidence in safety for the mine and the public.

The detection of rock fracturing is realized with appropriate sensors (velocity- or acceleration-proportional) which are installed in an array in the mine and/or at surface level (see Figure 2). The localization of seismic events is based on time differences between the sensors as well as on the detailed knowledge of local geology.

For signal transfer several methods are used: signals from underground are transmitted over long distances (up to 26 km) with the robust PFM (pulse frequency modulation) or digital via optical fiber. At the surface data transfer is realized as well via cable or wireless via WIFI or other mobile connections. For each monitoring system K-UTEC AG develops customized solutions, e.g. the construction of a special set of seismometers, acceleration sensors and modulation with ATEX admission for operation in explosive atmosphere. In addition sensors and transfer ways were secured against aggressive brines. With this set of devices the long-term seismic monitoring in the Bischofferode mine after quitting and closing of the shafts is possible.



Figure 2: Examples for sensors and data transfer of underground seismic monitoring

The data collection, archiving and other automatic or manual analysis is done at a key PC or server. Customized software provides an automatic first analysis of each registration and in case of exceedance of prechosen alarming conditions, an alert will be sent out. These alerts are a main safety measure for a mining company. Also the data of geotechnical devices (for instance inclinometers, pressure and level sensors) can be implemented into the monitoring systems, e.g. for active flooding or inflow surveillance.

## Case examples

### Case I: Monitoring of seismic activity through active flooding of a potash mine

The Volkenroda potash mine was mined from 1910 to 1990. One special characteristic, compared to other south-hercynian mines, is the depth up to 1000 m below ground and the increasing emergence of liquid and gaseous hydrocarbons. At closing time the mine was equipped with 3 shafts in Menteroda (Volkenroda) and Pöthen (Pöthen I and II). Between 1990 and 1998 the mine was closed which means all surficial installations were pulled down and the shafts were coffered. In 1992 the active flooding of the mine with solutions from the mining waste dumps through the still open shafts started. 1997 a flooding well for injecting the solutions after coffering of the shafts was drilled into the mine field. The injected dump solutions spread after a targeted saturation in a rock salt field as halite brine primarily within the geodesic lowest mine level (southeastern field - Südostfeld). After a further saturation of the injected solutions was no longer possible because of geodetic reasons the flooding was switched to the observation and flooding well near the village Urbach. By the way of changing the injection regime to the flooding well Urbach it was possible to inject the partly saturated dump solutions into a million square kilometer big mining field with saturated flooding solutions. With time the flooding solutions reached a level in the northern mining fields to allow overflow to the mining field Pöthen through the air gallery. 2013 a new surveillance well was drilled near the former shaft Pöthen to control the flooding of the Pöthen mine. It was equipped in 2015 with a combination probe which on the one hand side allows continuous monitoring of the brine level with a pressure sensor and on the other hand side detection of seismic signals with a borehole seismometer.

Seismic monitoring in the Volkenroda/Pöthen mine started at the end of 2002 with an array of 4 stations at the surface in the area of the Volkenroda mine. This array was extended with time to the Pöthen mine for monitoring the flooding extend as well as the seismic activity for prove of safety. Three vibration measuring stations according to DIN 4150-3 are installed for collecting evidence in case of intense seismic events. These tools for preservation of evidence with monitoring arrays as well as vibration measuring stations gained in importance throughout the last years.

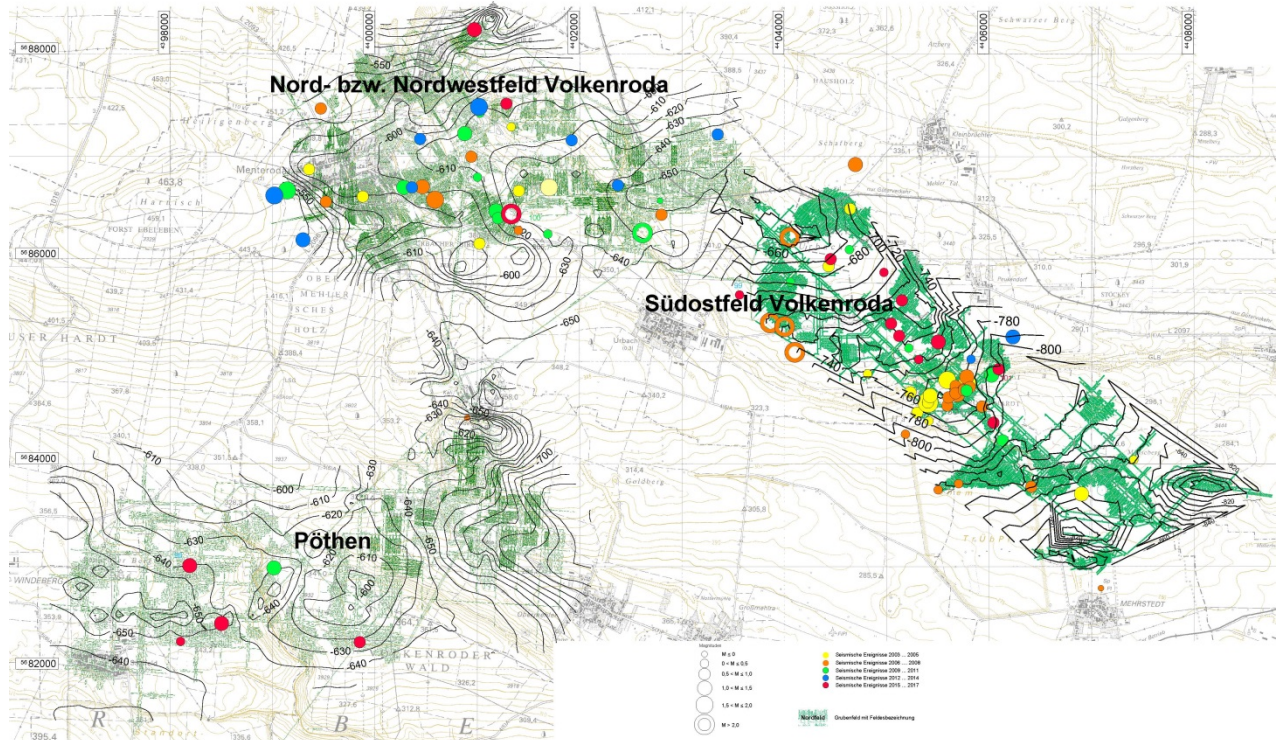


Figure 3: Seismic events and their development in the Volkenroda mine area since 2002

In Figure 3 the mining fields with the level curves (in mNN) and the seismic events recorded within the mining fields are shown. From this kind of map you can draw conclusions regarding the cause of the events and allows derivation of trends and prognosis for precarious areas. At first it shows that the main seismic activity until 2009 is concentrated within the eastern mining fields (Südostfeld). Here are the geodetic deepest parts of the mine. The event locations moved partly towards the west which can be correlated with the flooding extent. It can be assumed that the pillars of the hard salt area are imbrued and the partly open pillar area with the underlying Carnallite is influenced by the flooding. This leads to a partly liquid-induced acceleration of the convergence within the deposit and the activating of underlying and upper bed tectonic elements like the Schlotheimer Graben. For this reason seismic events up to a magnitude of  $M_L = 2.5$  (Iida) occurred.

Since 2009 an increase of the already existing seismic activity in the northern mining fields (Nord-, Nordwestfeld) started together with the rising of the injected solutions. So the seismic activity is directly tied to the flood extension line. The seismicity around the villages in this area is kept at a reasonable level because only saturated solutions flow into these mining fields. The overflow of the flooding solutions into the Pöthen mining field started later than expected in 2013. In the past two years number and magnitude of the seismic events increased naturally. In this area magnitudes up to  $M_L = 1.3$  were recorded. But also in the southeastern mining field (Südostfeld) and secondary in the air filled former mining areas of the northeastern mining fields (Nord-, Nordostfeld) a certain number of seismic events is perceived. This is caused by the areas strong tectonic precondition. The hercynian striking Schlotheimer Graben is located south of the mine and has some transvers faults and leads which cross the Volkenroda mine in north-south direction. This tectonic elements cause seismicity and its effects will last in parts after the safekeeping of the mine. The connection between flooding and seismicity is also clearly visible from the Benoiff-curve which shows the cumulative energy release as a sum curve over time (see Figure 4).

This graph is showing the success of the mine's safekeeping by flooding. The seismic activity decreased markedly in the nearly completely flooded southeastern field (red line) and reached a reasonable level of energy release affecting the surrounding villages. In the other mining fields the seismicity increased, but the energy release is slower and more balanced than in the southeastern field.

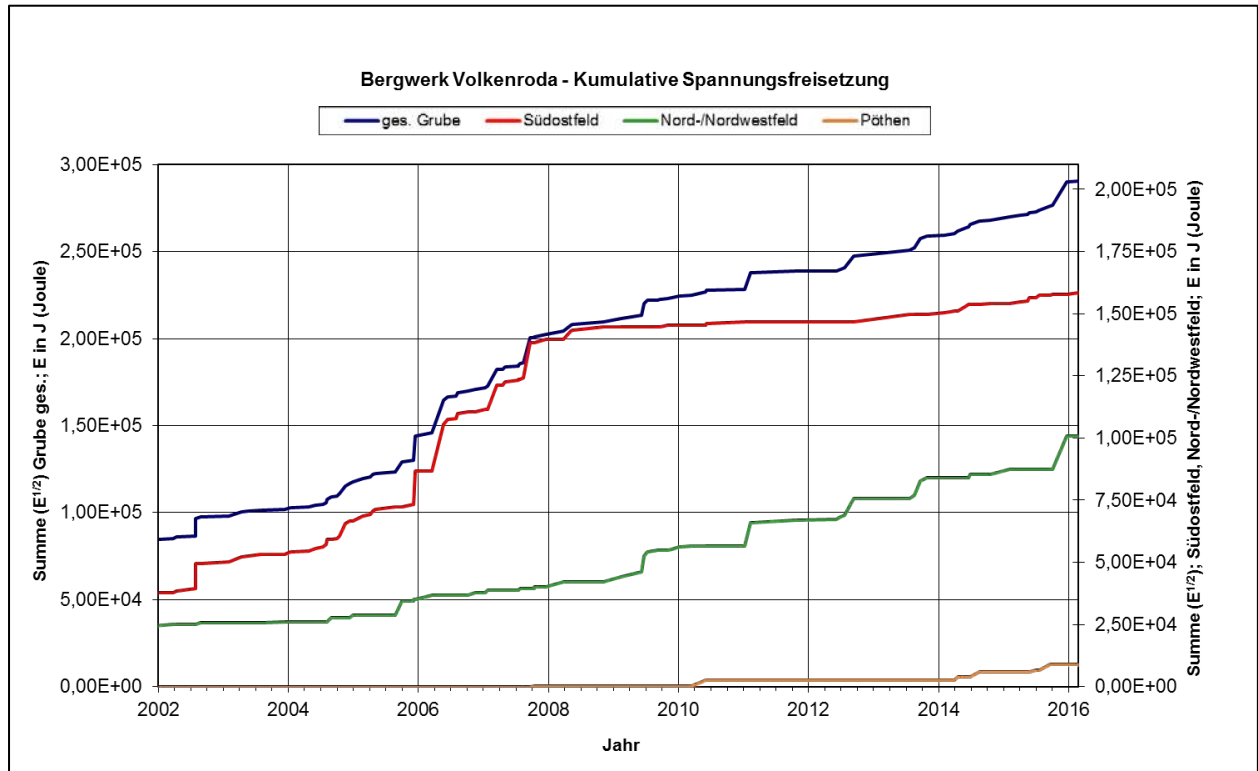


Figure 4: cumulative energy release for the Volkenroda mine 2002 –2017

### Case II: Monitoring of seismic activity previous and after the safekeeping of a Carnallite mining field

In the Bleicherode mine mixed salt and hard salt was mined in a depth of 550 m to 800 m since 1947. With decrease of the hard salt reserves at the end of the 1970's Carnallitite mining started. Different mining methods were used in several mining blocks: partly multi-floor mining as well as long chamber mining.

Caused by the extending mining field the subsidence rates and subsequent to this the seismic activity escalated at beginning of the 1990's. This is, for instance, visibly evident from the Benioff-curve (see Figure 5). From the results of the complex seismic, geotechnical and geodesic monitoring it was obvious that a collapse of the pillars in the Carnallitite mine field and the sudden subsidence of the overburden were very likely. This could cause a sudden energy release through seismic events up to a magnitude of  $M_L = 3.5$  to 4. Therefore the mining authorities declared that backfilling is mandatory for safekeeping of the hazardous areas.

Mainly flushing with non-mining waste was used, but in some parts "Big Bags" or drop stowing were brought in. Backfilling should stabilize the voids and reduce the subsidence of the hanging wall and the overburden. It minimizes the seismic energy release and the reactive open space to avoid a rock burst.

Backfilling was monitored continuously by a complex surveillance system with seismic sensors, a geomechanical measuring program (convergence and in-situ stress measurements), subsidence leveling, gas monitoring and methodical stowage testing. The gobbing is nearly finished in this mining field by now.

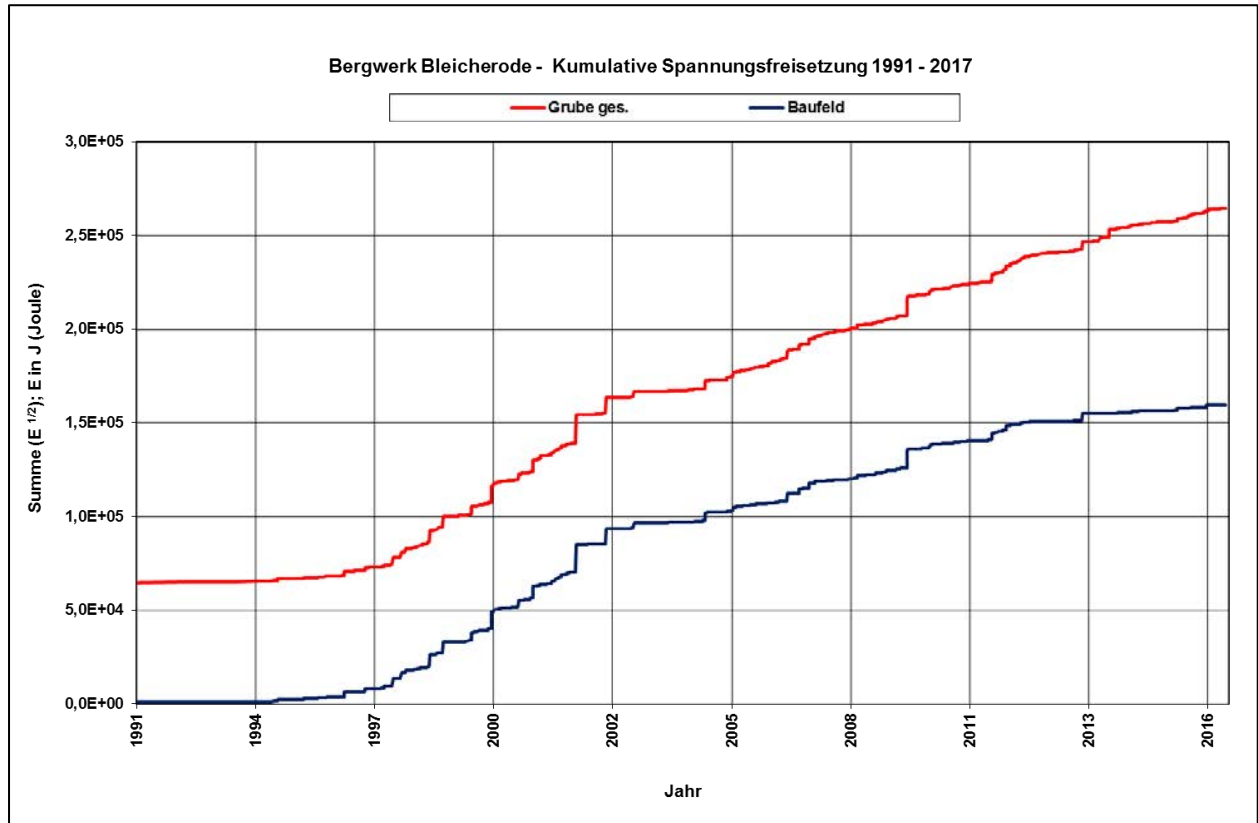


Figure 5: cumulative energy release of the Bleicherode mine 1991-2017

At the beginning of the 1990's the seismic activity was increasing obviously. Magnitudes reached from background seismic events with  $M_L \leq 0$  to strong far-reaching rupturing with  $M_L = 2.3$ . In the period from 1995 to 2017 nearly 1400 seismic events were detected, mostly in the deposit layer. As a main reason for seismic events mining induced and deformation driven ruptures in the deposit and the influence of tectonic elements in the overburden can be seen. With time and ongoing backfilling into northern direction also a northwards movement of seismic events was observed. This means the seismicity, resulting from material soaking and displacement of stress through backfilling, increased at first. Since 2012 seismic activity in this mining field is reduced not only in number of events but also in energy release (see Figure 7). For instance, since 2013 no seismic event with a magnitude of  $M_L > 1$  was observed. So the positive stabilizing effect of backfilling is proved by reduced seismicity. It's also reflecting in the subsidence rates. They were reduced from 150 mm/a in the beginning to about 20 mm/a in the central area of the mining field (see Figure 6). The total subsidence now reached 2.40 m.

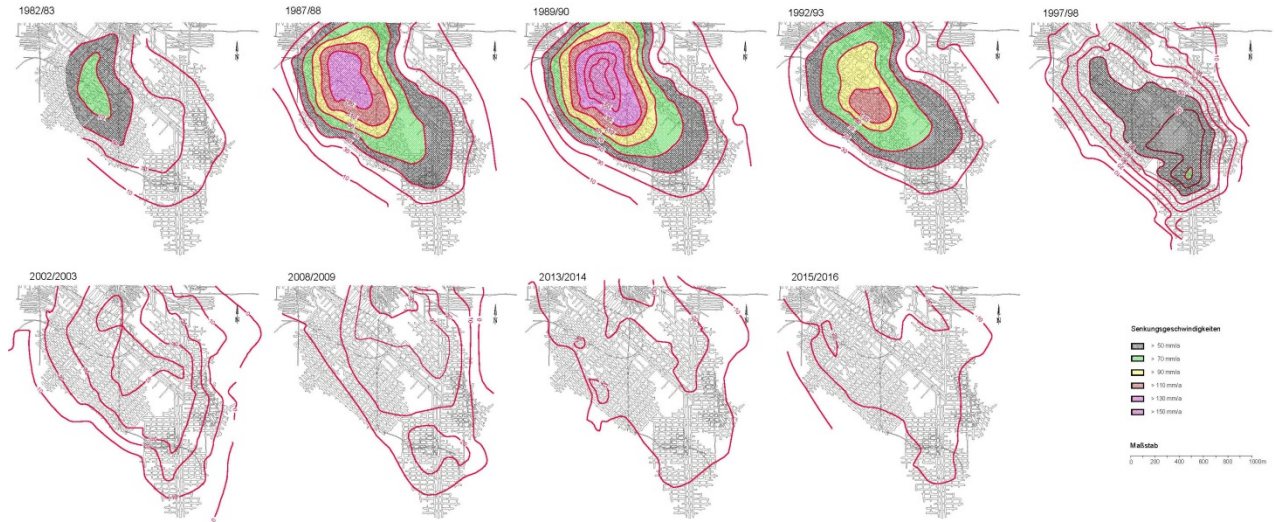


Figure 6: subsidence rates on the surface for the Carnallite field of the Bleicherode mine from 1982-2016

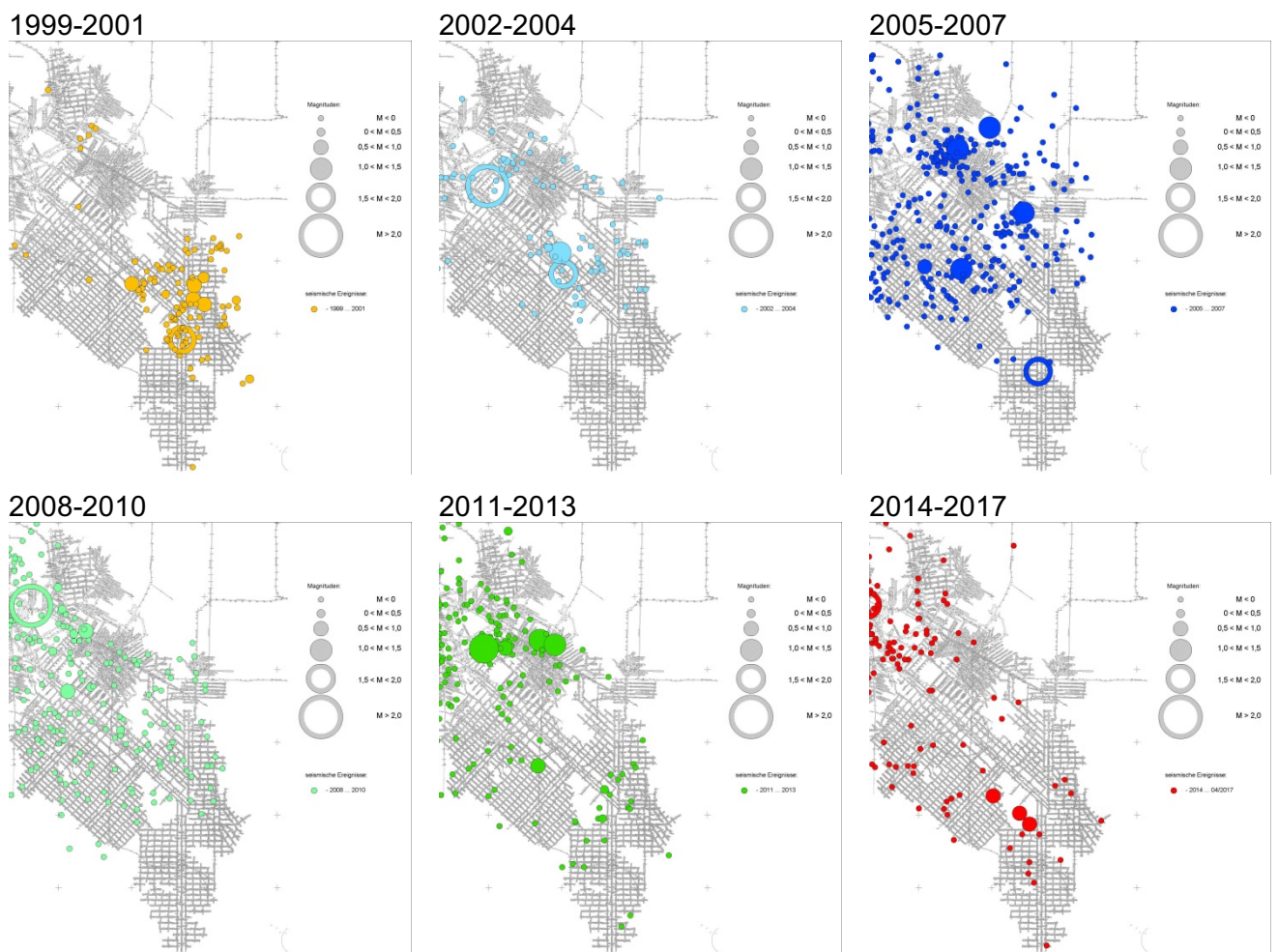


Figure 7: development of the seismic activity of the Carnallite field of the Bleicherode mine from 1999-2017

## Conclusions

A complex seismic and geomechanical monitoring gives the tools for a reliable estimation of potentially hazardous conditions for stability of a whole mine or parts of it as well as for controlling of later redevelopment measures for removing or minimizing sources of danger. This technique is successfully used in the south-hercynian potash mine area since decades in the mining, backfilling and post-closing phase. Evolving destabilizing moments and the resulting static and dynamic implications as well as the stress at the surface or on the mine's structure can be accurately assessed with the monitoring. It's possible to induce timely measures for safekeeping and to control them in the right priority. In the post-mining phase seismic monitoring gives the possibility for prove of long-term safety. One key advantage of this method is operation over long periods without even entering or driving at the surveyed area.