Geophysical methods as one way to detect and assess sources of danger in engineering and mining

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ABSTRACT: The application of geophysical methods in civil engineering and mining becomes more and more significant. The combination of geophysical data with classical geotechnical measurements can greatly improve the quality and reliability of investigations e.g. regarding stability of mines, dams or buildings because of the high data density provided by geophysical methods. In that way geophysical applications can be an important and in some cases essential source to early detect potentially dangerous conditions both in mining and engineering. A number of case examples to demonstrate the application of geophysical monitoring and exploration techniques such as engineering seismology, sonar and ground penetrating radar respectively for the assessment of the condition of mining fields, the assessment of the geological barrier of mining fields and for investigations of stability issues of dams and dikes.

1 INTRODUCTION

The application of geophysical methods in civil engineering and mining becomes more and more significant. Reasons for that are for example the non-destructive determination of properties of the investigated object as well as the possibility to describe an investigation area by geophysical methods without placing sensors directly in that area.

Independent of what geophysical methods are applied for, i.e. building ground investigations, inspection of dams and dikes or exploration and monitoring in mines, the aim is in the first place the exploration of geological structures and the determination of physical parameters of the rock formations to help solving geotechnical problems.

In engineering geophysics the question about the quality of building foundations, dams and others is frequently asked when damages are either observed or are to be expected after external stress like for example the inspection of dams and dikes after a flood.

In case of mining, geophysics can be applied both for exploration purposes and for monitoring of the geomechanical conditions. In this regard geophysical measurements can provide important information to early recognize potentially dangerous conditions. From the intensified exploitation of mines as well as from the aftertreatment phase or secondary use of the chambers after the mining result several sources of danger especially in potash and rock salt mining:

- destabilization of mining fields or parts of mining fields and resulting inadmissible dynamic stress and strain at the surface

- inadequate thickness of the protective layer or geological barrier for the protection against gases and fluids during mining and the use of the mines afterwards

- weakening and disintegration of the contour of the mine workings with a possible reduction of safety at work

The sources of danger in the field of engineering result essentially from:

- undetected near-surface structures, especially cavities

- material inhomogeneities in construction

The following case examples demonstrate the application of geophysical monitoring and exploration techniques such as engineering seismology, sonar and ground penetrating radar respectively for the assessment of the condition of mining fields, the assessment of the geological barrier of mining fields and for investigations of stability issues of dams and dikes.

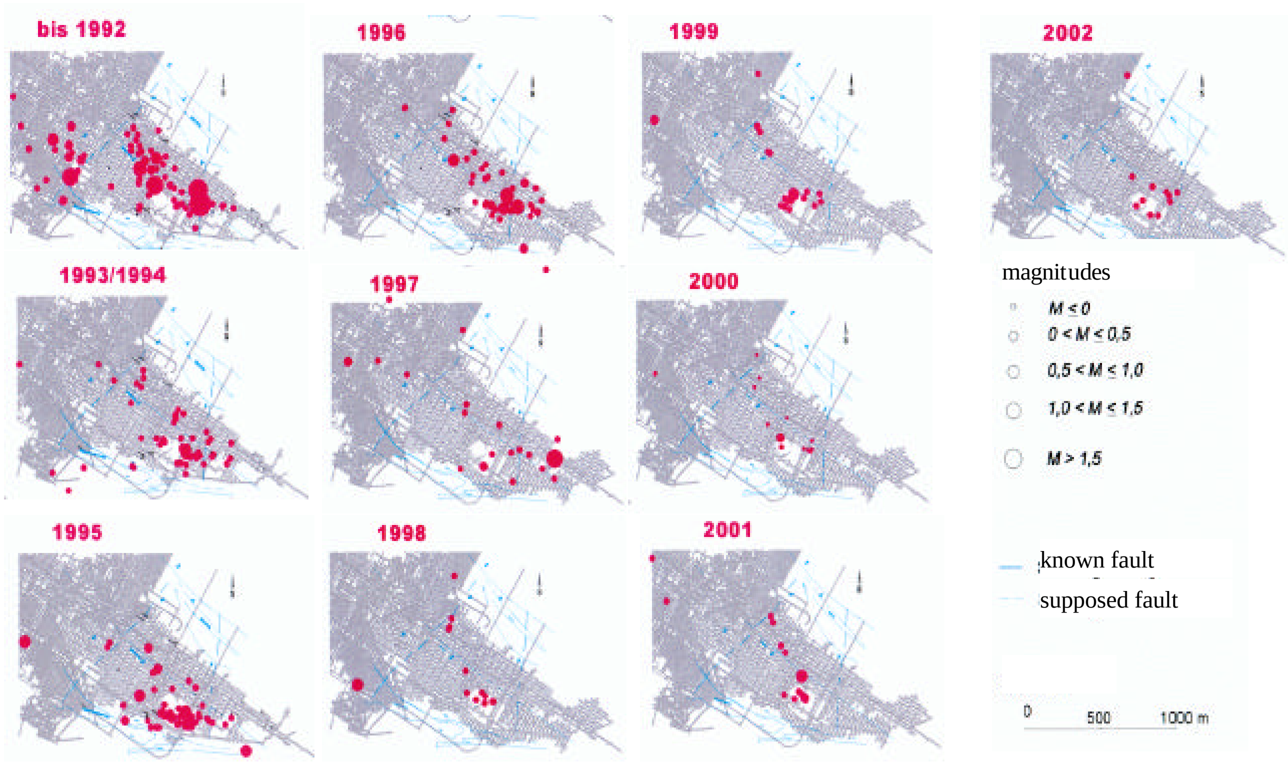


Figure 1. Development of the seismicity of a Carnallitite mining field during (1991-1996) and after stabilization measures

2 CASE EXAMPLES

2.1 *Stabilization of a carnallite mining field*

The field was mined between 1982 and 1991 and started to show signs of a rapidly increasing destabilization in form of an increasing seismic activity with magnitudes larger than 1.5 and high deformation velocities already during the last years of active mining. By 1991 the geomechanical condition of the field had reached a dangerous level of weakening and in parts almost disintegration of pillars. To avoid the collapse of the entire field, it was to be stabilized by quickly refilling the remaining chambers with rock salt. The backfilling and stabilization of the field was carried out between 1991 and 1996.

Figure 1 shows the development of the seismicity over the years from the beginning of the stabilization measures. From underground deformation measurements but also especially from the distribution of the seismic events in the field a priority list of which areas in the field had to be treated first could be derived. Moreover, the combination of deformation and stress measurements and seismic monitoring made it possible to identify especially weakened zones where special precautions for safety at work had to be considered. In that way the deformation processes were significantly slowed down resulting in a notably reduction of strong seismic events almost immediately after the backfilling had started as can be seen in Figure 2.

2.2 *Stabilization of a mixed salt field*

This mining field was in production between 1978 and 1991 and in parts mined in up to three levels. After the closure of the mine in 1991, the field was left open but still in stable conditions, thus no backfilling of the field was planned. The field was abandoned while other parts of the mine were used as an underground waste disposal site. The situation of the mining field changed, when the field showed a sudden appearance of seismic activity in 1996. A series of strong seismic events with magnitudes of up to 2.0 were located in the beginning preferably in the overlaying horizons of the mining field.

Figure 2 shows the depth distribution of seismic events on a cross section on an East-West profile through the mining field. The distribution of the epicenters within the field is shown in Figure 3. The vast majority of the seismic events is concentrated on lines which can be related to local tectonics.

According to the distribution and strength of the seismic events a risk of the opening of fluid migration paths into the salt complex and thus the loss of the integrity of the geological barrier had to be considered. For that reason, it was decided to reopen the field and stabilize it by backfilling of rock salt analog to the previous case example. At that time the information from the seismic monitoring were the only indications of a possible dangerous development. Only limited other geotechnical data could be obtained from the field because of it‘s inaccessibility.

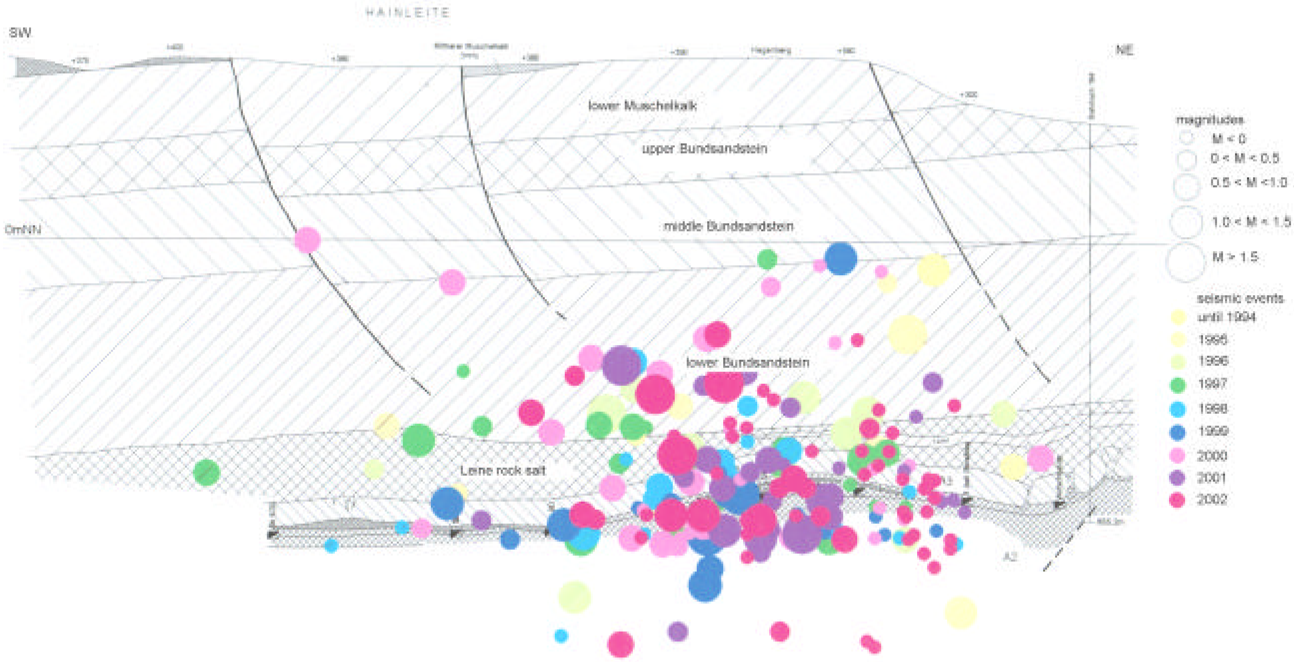


Figure 2. Cross section through the mining field and depth distribution of seismic events

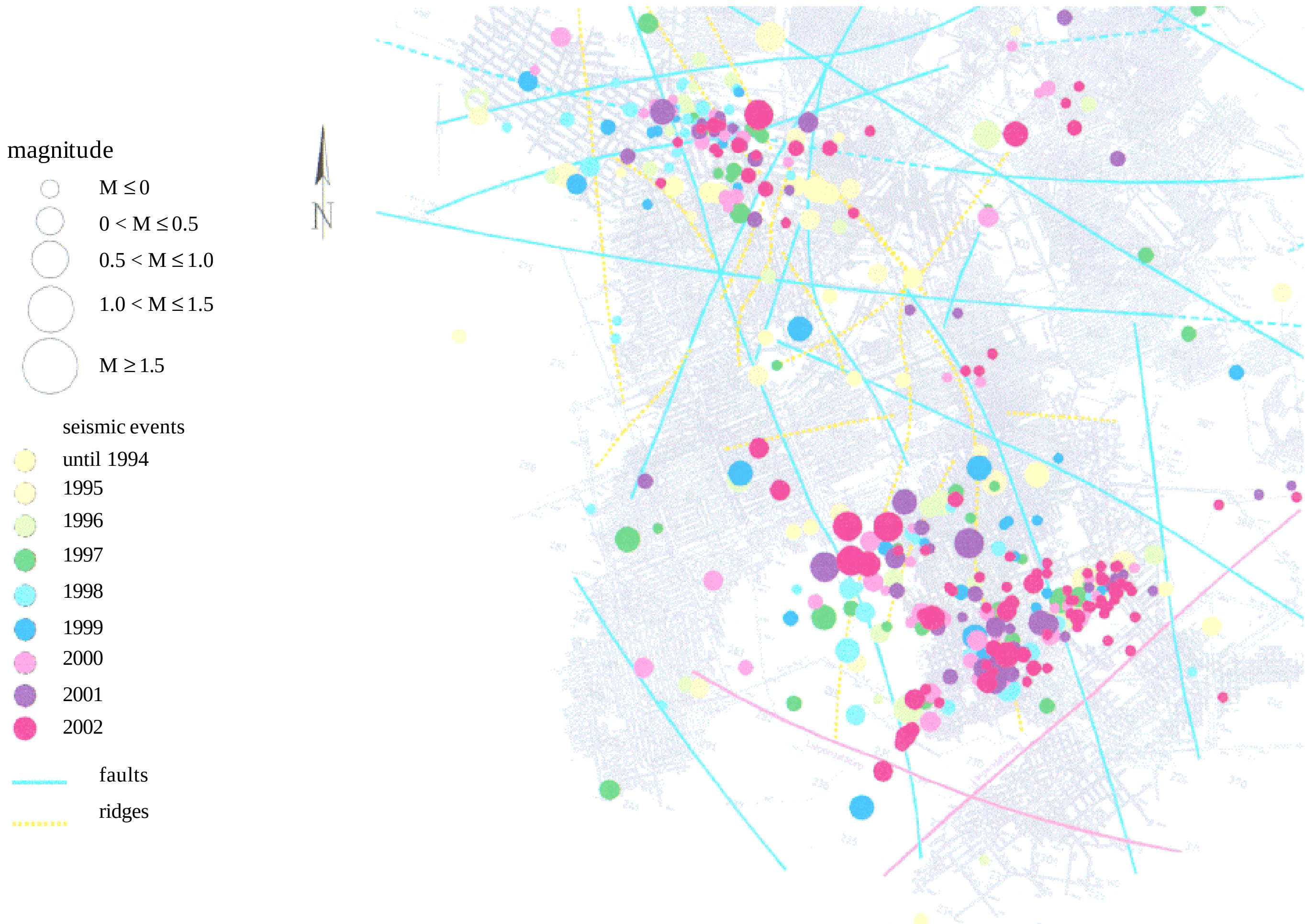


Figure 3. Distribution of seismic events in a mixed salt field. The majority of the events are located at structures related to local tectonics.

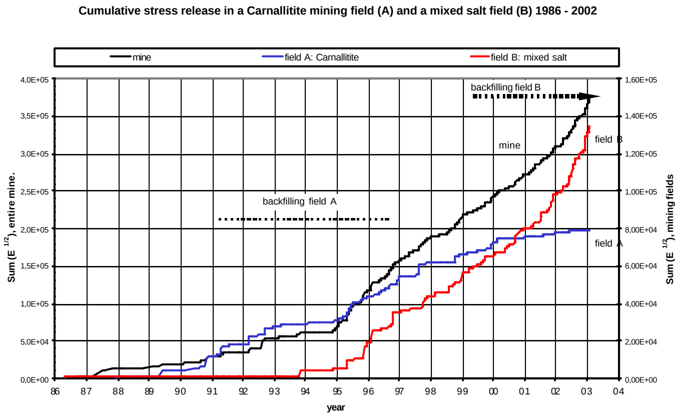


Figure 4. cumulative stress release of a carnallitite mining field (A), a mixed salt field (B) and the entire mine computed from seismic events according to Benioff (1951)

The stabilization measures started in 1996 are still ongoing.

Beside the alignment and grouping of the seismic epicenters along local faults and ridges as can be seen in Figure 3, the calculated focal parameters such as stress drop, dislocation, fault plane size and released seismic energy can be directly used for further geomechanical assessments.

An other way of characterizing the development over time of the field's condition by the observed seismicity is shown in Figure 4. There, the cumulative released seismic energy or respectively the square root of the energy is plotted over time.

The slope of this curve is related to the amount of stress released by the seismic events according to Benioff (1951). The shape of the curve gives information of how the stress is released. A high number of small events will result in a rather smooth curve while a small number of strong events would give a blocky shape. A change in the mean slope of the curve indicates a change in the characteristics of the deformation processes. If a long observation series of the seismicity in an specific area is available and under the assumption that the general deformation processes do not change in that time, the Benioff-curve also allows for an estimate of the maximum magnitude to be expected in that area (Benioff, 1951).

Figure 4 shows the cumulative stress release for the mixed salt mining field and in comparison the stress release for the previous discussed carnallitite mining field as well as for the entire mine. The sudden activation of seismicity in the mixed salt field (field B) on a high level in 1996 can clearly be identified in the curve. Since then, the seismicity remained on a high level and is lately even further increasing (increasing slope of the curve), which suggests that the ongoing stabilization measures have not yet taken any effect. Moreover, the deformation and disintegration of the field seems to accelerate. The Benioff-curve of the carnallitite field (field A) on the other hand shows a notable reduction of the cumulative released stress in 1993, already 2 years after the beginning of the stabilization measures. The seismic activity is reactivated in 1995 (see also Figure 1), but with smaller magnitudes of the single events than before (smooth curve). From 1998 on the stress release is slightly reduced. Since 2000 a seismic activity on a constant low level can be observed indicating that the deformation processes of the field have nearly come to an end – more than 3 years after finishing of the backfilling. In this regard and especially also because of the multi level mining of the mixed salt field (field B), the deformation processes of the mixed salt field can be expected to remain on that high level for the next few years.

2.3 *Application of georadar and sonar in mining*

Beside passive seismic monitoring, active geophysical exploration methods can also provide valuable information for the geomechanical assessment of a mining field. Especially for salt mining both radar and sonar are well suited to easily cover large investigation areas.

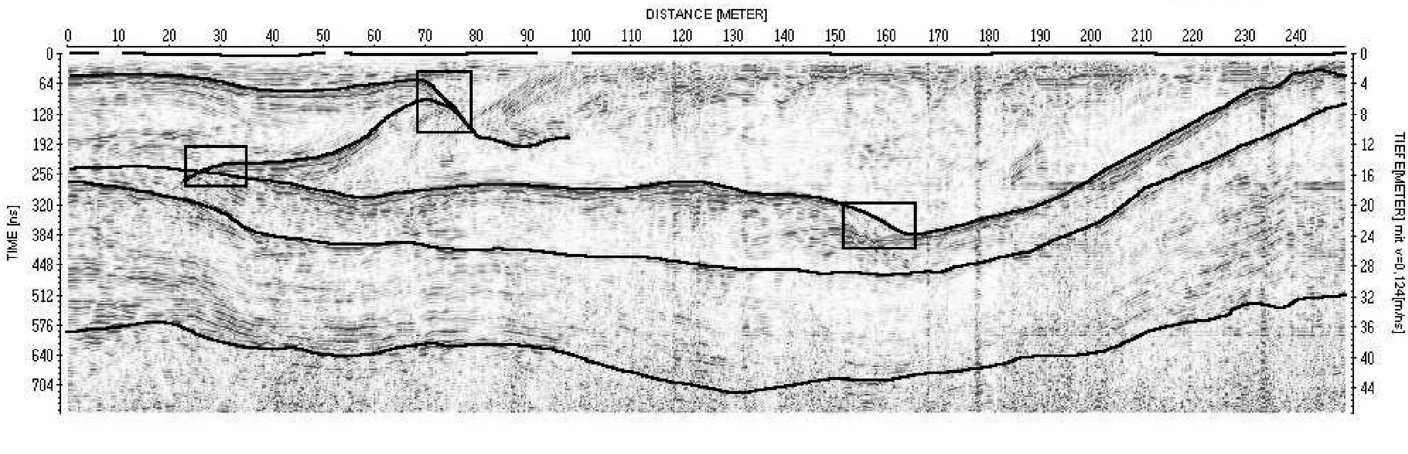


Figure 5. Radar investigation in a mine to investigate the thickness of the protective layer to the main anhydrite.

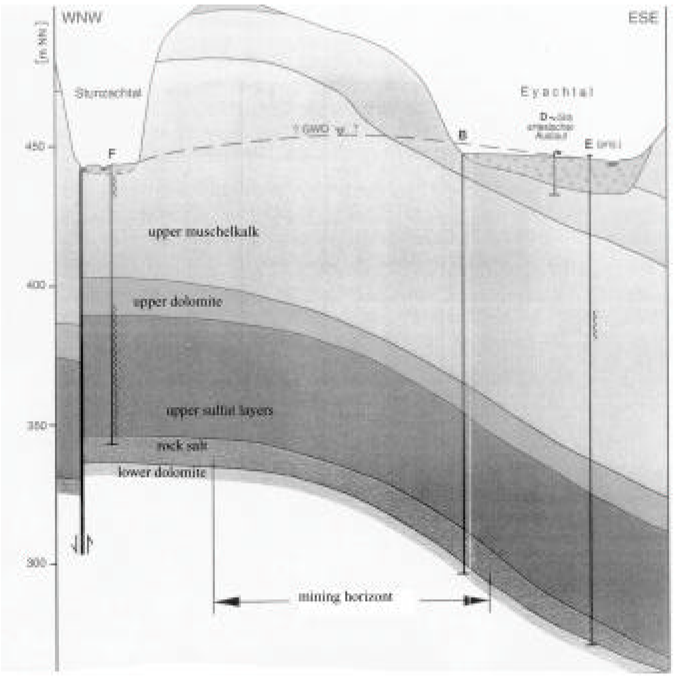


Figure 6. Cross section of the geology of the mine

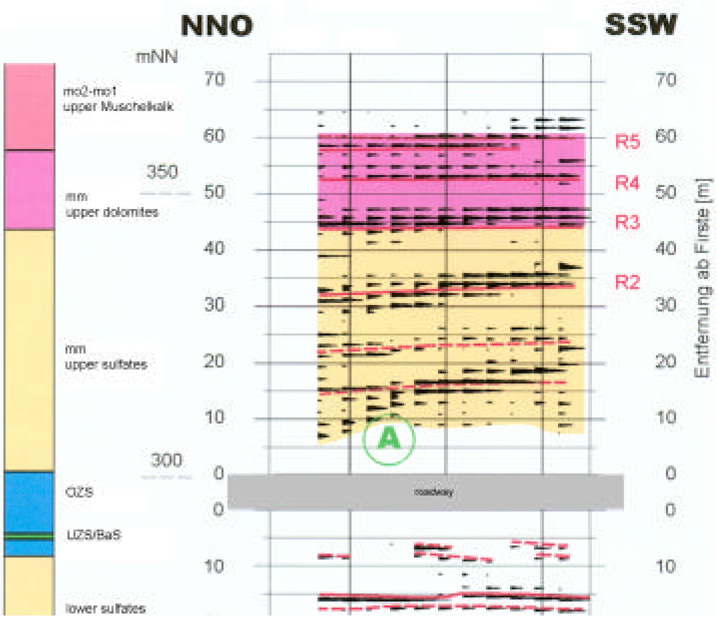


Figure 7. Results from sonar measurements in correlation with a nearby borehole

Both methods are applied from e.g. roadways within the mine for:

- investigation of thickness of protective layers, both below and above the mining horizon
- exploration of geological structures
- investigation of the contours of the mine workings for safety reasons
- estimation of thickness and integrity of horizontal pillars in case of multi-level mining.

Figure 5 presents a radargram of an exploration of the underlying main anhydrite in the same mixed salt mining field from the previous case example. The main anhydrite in the area is gas bearing (methane) and a minimum distance of 15 m has to be kept for safety reasons (i.e. gas leakage, outbursts).

Because of the high contrast of the electric properties between the anhydrite and the neighboring salt as well as the high attenuation of electromagnetic waves in the anhydrite, virtually no reflections are received from beneath the main anhydrite. Thus, the salt-anhydrite boundary can be identified as the last detected reflection. In Figure 5 the top boundary of the main anhydrite is found at depths greater than 30 m from the floor of the mine workings hence the safety requirements are fulfilled. The radargram also reveals internal structures of the salt complex such as a tilted fold, indicating a much more complex geology than previously assumed.

A different situation but with similar exploration tasks can be found in a rock salt mine situated in the triasic (Muschelkalk) complex. The mining horizon is only about 130 m beneath the surface and the thickness is rather small with just around 10 m. Because of the shallow depths and thus the close vicinity of the mining horizon to the groundwater bearing formations special care has to be taken to maintain an appropriate thickness of the geological barrier.

Figure 6 shows a cross section of the main geological situation. The task for the geophysical exploration was to detect the layer boundaries of:

- rock salt / upper sulfates
- upper sulfates / upper dolomites
- upper dolomites / upper Muschelkalk

The upper dolomites and the upper Muschelkalk layers are already counted to the groundwater bearing formations. The investigations were problematic because the fine layering of the formations, especially the large number of thin shale an anhydrite layers attenuated and scattered most of the energy of the transmitted signals. The application of radar was in that case limited for only shallow investigations since the depth penetration was strongly reduced to just a few meters because of the fine layering. Although the sonar investigation was also effected by the layering, the penetration depth was still sufficient to complete the exploration tasks. The boundary between Upper Sulfates and Upper Dolomites, which was of the main interest, could be clearly detected by a dense series of reflections (Fig.7). The estimated layer boundary could be verified by a nearby borehole.

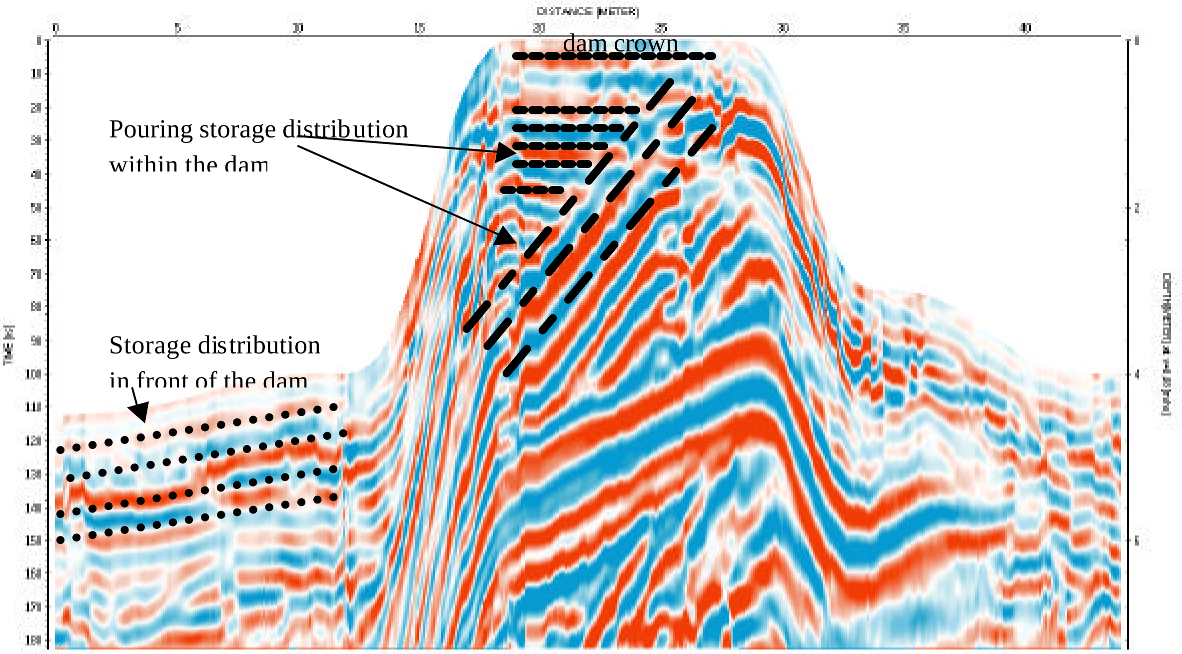


Figure 8. Cross section through a dam with georadar, measured with 100 MHz antenna

2.4 *investigations of dams and dikes*

The last case example demonstrates the application of geophysical methods in the engineering sector.

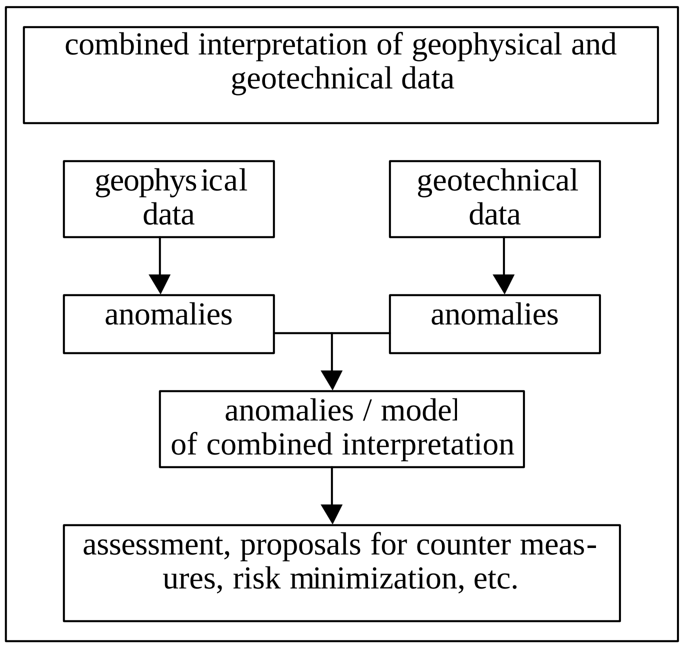
The August 2002 flooding of the river Mulde created a 235 m wide and 7 m deep erosion channel, leading to the breakthrough of the river into an open-pit coal mining field and washing away the street that ran in between. A dam was immediately constructed already during the flood to limit the inflow into the coal pit. The dam was built up with porphyr gravel of mixed grain size. Because of the difficult situation during construction, the new dam had to be inspected by direct and indirect means with respect to stability and tightness after the flooding.

Geoelectric and Georadar measurements were carried out both along and perpendicular to the dam axis. The geoelectric profiling enabled the differentiation of the dam body from its foundation and underlying formations (e.g. sand, gravel, clay and coal). In addition, the dam and the area in front and behind was probed by boreholes, which were also used to calibrate the results from the electric measurements

The radar measurements were used to determine internal structures of the dam. A radargram of a profile crossing the dam is shown in Figure 8. A number of dipping reflectors can be identified within the dam, which result from the construction of the dam (sideways pouring of the gravel) and in that case imply the risk of future sliding planes.

3 CONCLUSIONS

The data geophysical methods can be an essential contribution to classical geotechnical measurements for the detection of sources of danger in case of short term changes of the geotechnical situation as well as for the assessment of long term stability issues:



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