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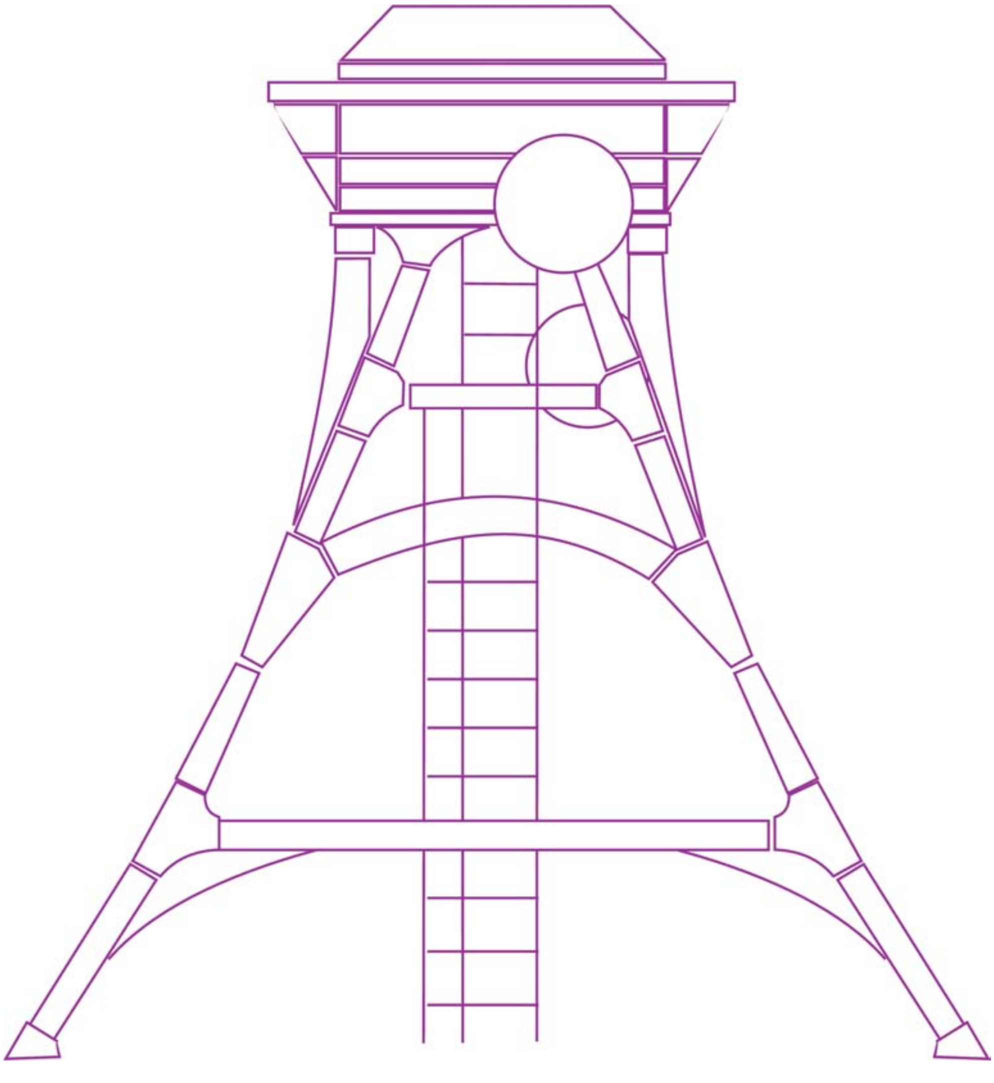


Geophysical Measurements

Geophysical Measurements

Kali – Umwelttechnik GmbH (K – UTEC)
Am Petersenschacht 7
99706 Sondershausen
Germany

Phone: ++49 – 3632 - 610 - 0
Fax: ++49 – 3632 - 610 - 105
e-Mail: kutec@kutec.de

Managing Director: Dr Heiner Marx
Dr Holger Thoma

Sector: Geophysics

Person in charge: Dr. M. Jordan

Phone: ++49 – 3632 - 610 - 190
Fax: ++49 – 3632 - 610 - 105
e-Mail: geophysik@kutec.de

Specialist for the field of **geophysical investigation**
of Potash mines:

Cert. Geophys. Thomas Schicht

Gesellschaft für Verfahrenstechnik
Abfall und Altlasten
Umweltanalytik
Geophysik und Geotechnik

K - UTEC GmbH
Am Petersenschacht 7
99706 Sondershausen

Tel.: ISDN **03632 610-0**
Fax.: **03632 610105**
E-Mail **geophysik@kutec.de**

The Ultrasonic-Seismic Measuring System "KUTEC 4"

< Measuring application for Windows 95

< Digital configuration of the measuring system

< The amplification of each individual channel can be calibrated / linear or weighted by an exponential function

< Batch processing with arithmetic calculation of the mean value

< Repetition frequency 0,5 - 1,5 Hz

< Measuring frequency 10 - 60 kHz

< Representing of the registered signals in a diagram windows

< Burst oscillations of 2^0 bis 2^7 oscillations

< Online-handling of maximal 8 digital channels

< Built-in C 32-processor and internal 170 MB hard disk

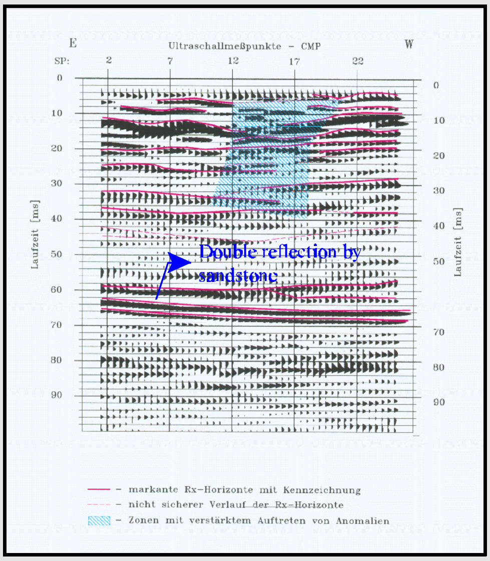
< PC-connection via Ethernet

< Portable PC with
  - < hermetically sealed metal case and foil keyboard
  - < FFT-screen 10,4" / resolution 800 * 600 pixels; 262.000 Colours
  - < Prozessor AMD 5x86 mit 133 MHz clock rate / harddisk: 1,2 Gbyte und 16 MB RAM
  - < Ethernet interface for twisted pair cable

Equipment with PC and ultrasonic transducer –

The measurement

Measuring exemple: ultrasonic-migrated-time intervall –



Tasks for the measuring system in solid rock are, for example:

- from out of tunnels and boreholes -

! Geological exploration of structures

! Exploration of leaching cavities and crack zones

! Differentiation of fault zones

Main building from the K-UTEC GmbH

The Ultrasonic-Seismic Measuring System "KUTEC 4"

Ultrasonic measurements from out of the tunnel with high-performance transducers into the

< **advance of the face**

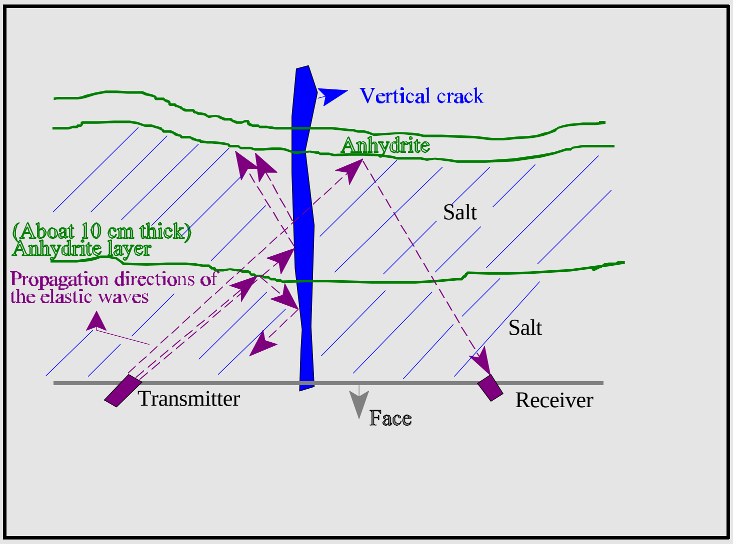
< **roof**

< **bottom**

of the solid rock

Transmitter coupled to the salt rock

Geological Model



Exploration of vertical or very steeply inclined cracks by means of specific measuring methods

Ultrasonic-seismic borehole method –

The ultrasonic borehole probe // transmitting end

! Required borehole diameter 64 - 70 mm (to the August 1998, then 64 - 120 mm)
! Exploration of the unworked area up to 100 m length of the borhole (technique for longer boreholes - 500 m - are in the state of development)
! Exploration radial to the borehole
! Tasks are the same as in measurements from out of the tunnel

The borehole probe –

- Sonar -

Kali- Umwelttechnik GmbH
Sondershausen

Sonar Method / Ultrasonic Seismic

Geophysical Exploration in Potash and Salt Mining

References and Equipment Technology for Kali-Umwelttechnik GmbH Sondershausen

1. Experiences and References of Kali-Umwelttechnik GmbH in Using the Sonar Method in Potash and Salt Mining

The firm of Kali-Umwelttechnik has many years of experience both in the field of development and implementation of ultrasonic measuring methods, and also in the design and interpretation of ultrasonic seismic measurements.

The first ultrasonic seismic measurements were carried out back in 1963 in the mines at the Völkershausen / Pöthen mining district.

The development work was begun at the former Potash Research Institute in the field of mining safety research and pertained to ultrasonic apparatus for measurements on native bedrock and for taking surveys of caverns.

Based on the acute hydrological problem constellations of Potash Mining in Central Germany, the activities in the area of development of a sonar device and the implementation of ultrasonic seismic measurements were increased in the 1970s.
The following sections provide a description of the sonar device developed by Kali-Umwelttechnik GmbH and of several, selected exploration examples.

The digital sonar apparatus that we are using is a 4th generation, proprietary apparatus for exploration missions specifically in the field of potash and salt mining. With regard to sonar measurements, frequencies from 20 - 50 kHz are employed, depending on the required resolution. The sonograms are presented continuously on the monitor. The data is saved in SEG-2 format and is then subjected to seismic data processing (standard processing, see Figure 1

References:

Exploration site	Objective
Potash mine Werra Merkers pit / Kali und Salt GmbH / Kassel	Exploration of the salt table
Potash mine Werra Unterbreizbach pit / Kali und Salz GmbH / Kassel	Geomechanical studies with ultrasonic Crosshole measurements
Potash mine Werra Springen pit / Kali und Salt GmbH / Kassel	Exploration of cleft systems and lye deposits, including cross site 23 – hydrological hazard
Bischofferode mine / GVV mbH Sondershausen	Determination of shield layer thickness, stratigraphic measurements through the grey salt pelite, repeat measurements in 6 - 8 week intervals, **starting in 1985 continuous ... 2000,** exploration of the salt table in the vicinity of the North Field

"Glückauf" mine / GVV mbH Sondershausen	• Structure exploration of fault zones in the East Field I (stratigraphic measurements) down to the Leinerock salt; • cyclical measurements to determine any change in safety pillar between the "Glückauf" and Immenrode mining fields (Grubenfeld Immenrode submerged) • Measurements for shaft condition analysis, shaft III
ERA Morsleben / BfS Braunschweig Marie pit	Geophysical studies in main cross-cut level 4. Floor of Bartensleben shaft and 360 m floor of Marie shaft
Russian Potash Industry-Uralkali Beresniki and Solikamsk shaft systems	Measurement tasks lasting several weeks during **1987,1988, 1990, 1995 and 1999** for exploration of cleft systems in the overlying layer, hydrologic hazard, in 1987 one of these cleft systems stratigraphically above led to flooding of the Beresniki III pit, subsequently the above-referenced measurement tasks were carried out
Bischofferode mine / GVV mbH Sondershausen Bischofferode spoil bank	Exploration of hollow cavities in the spoil bank (see References), 1986 ... 2000
Foundation subsoil Architectural Offices of Büchner & Menge Stump Bohr GmbH	Various special studies with ultrasonic-seismic methods for examination of foundation subsoil and in the speciality of monument preservation, 1994
Cavern surveys Bleicherode mine Bernburg salt mines	Measurements using ultrasonic echo probes in caverns in the salt field at Kehmstedt, Knetsch and in Staßfurt
Research mine Forschungsbergwerk Asse / Remlingen	Ultrasound investigation of fault zones, e. g. small tectonic elements, accumulations of lye and migration paths 1992 and 1996
Stone salt plant Heilbronn of the Southwestgerman Saltcompany	Ultrasound investigation of the hanging und lying wall in saline environment, 1996, 2000
Stone salt plant Stetten / Wacker-Chemie	Ultrasound investigation of the hanging und lying wall in saline environment, 2000
Stone salt plant Bernburg / Kali und Salt GmbH Kassel	Ultrasound investigation of the hanging und lying wall in saline environment, 1999, 2000
Stone salt plant Klodawa / Poland	Ultrasound investigation of the hanging und lying wall in saline environment, 2000

2. The Sonar Equipment System Used by Kali- Umwelttechnik

The basic gear on the current special equipment system specifically for Potash and Salt mining was developed at the Potash Research Institute, and later, after the founding of the firm of Kali-

Umwelttechnik, the development was continued until today's technical standard was reached. Figure 2 presents the equipment system using ultrasonic converters and the bore hole probe. A minimum diameter of 64 mm is required for employment of the borehole probe. Appropriate locations have to be milled in order to couple the ultrasonic converter in the vicinity of the mine shaft.

The primary uses of the method in Potash and Salt mining are:

- Detection of cleft systems or cleft zones or of lye-filled cavities in the solid rock through examinations in the zone in front of the face, in the overlying or underlying mountain.

- Detection of geological fault zones, e.g., in the basal anhydrite or in the primary anhydrite, partly in conjunction with the seismic methods in a frequency range of 2 kHz.

- Determination of thickness of lye safety pillars (also for continuous leaching)

- Determination of thickness of safety layers, primarily for gas-bearing and lye-bearing horizons.

The advantages of the seismic ultrasonic reflection principle in a frequency range of 20 - 50 kHz reside in its very high resolution.
The use of the sonar method is particularly helpful when the more time-efficient radar method has reached its physical limits. This is the case when relatively thick layers of clay, lye deposits, significant moisture in the rock, etc., absorb so much electromagnetic radiation that radar will only work down to very short ranges.
These particular anomalies can be transited by the ultrasonic waves almost without any notable attenuation.

- **Some data on the principle and on the technical structure of the ultrasonic measuring system:**

  The apparatus was developed specifically for rough working conditions like that often encountered especially underground in salt mining. It is a very sturdy and easily transported device.

  The ultrasonic method has an exploration range of up to 200 m in solid rock.
  The measurements are carried out as sonding probes (real-time measurements) with the advantage that at these radiation angles, no notable surface or transversal waves are received. Figure 3 shows an ultrasonic receiver connected to the salt rock.

  The equipment system has the following technical data:

Total weight	About 25 kg
Dimensions	
Length	430 mm
Width	240 mm
Height	355 mm
Electrical Parameters	
Operating voltage	12 V
Maximum power consumption	8 A
Average power consumption	About 60 W
Acoustical pulse power	About 500 W
Maximum amplification of the receiver	About 100 dB
Number of channels	2
Operating frequency range of the transmitter	18 ... 60 kHz
Operating frequency range of the receiver	18 ... 60 kHz
Time-dependent, automatic amplification control	
Burst width	operator adjustable; 1 ... 5 ms
Burst frequency	default setting about 1 Hz
Converter	Proprietary design using sandwich construction with differing resonance frequencies
Penetration range into rock salt	up to 200 m
Data format	SEG-2 – format
Presentation of amplitude spectrum / generation of an overall signal from single signals with differing burst	

3. Explanation and Discussion of some Sample Measurements

We present below a brief selection of exploration opportunities that will use the sonar method.

Exploration example 1 (Figures 4 and 5)

During operation, but also as a part of the preservation of salt mines, it is often necessary to determine the thickness of the stratigraphically higher protective layer and in particular at the boundaries of the deposit, in accordance with the geologic model of Figure 4.
A typical, processed seismic depth cut is shown in Figure 5. As a rule, the measurements are begun in the vicinity of a rising bore-hole, so that the data can be readily correlated. The rock salt / grey salt pelite boundary (T3) - reflector Rx_1; primary anhydrite (A3) / Leine rock salt (Na3) - reflector Rx_2 and Leine rock salt (Na3) / red salt pelite (T4) - reflector Rx_3 can be very easily detected. The thickness of the Leine rock salt in this case is still 76.5 m when using a speed of sound in the layer of 4.5 km/s. But in addition, anomalies are visible both in T3 and also in A3 (underlying regions) which are attributable to clefts.
The last reflector is located at a distance from the crest of 188 m. In this case, we are already dealing with an indication of variegated sandstone.

Exploration example 2 (Figure 6)

This exploration mission includes the same problem constellation as exploration example 1, but was surveyed by the use of borehole probes. When taking measurements with the borehole probe, as a rule it is assumed that the exploration range is somewhat smaller due to the less favourable coupling conditions. This disadvantage is somewhat compensated by the increase in the stacking rate. In the present example, the necessary range is still 40 ms, which corresponds to an exploration distance of 91 m.
The fault zone is clearly discernible, and it penetrates both the primary anhydrite (A3) and also the Leinerock salt (Na3). The thickness of the Leinerock salt is no more than 25 m.

Exploration example 3 (Figure 7)

This example pertains to the exploration of the water protective layer. The ultrasonic seismic plot is presented next to the depth plot. In spite of numerous passes through the layer, the possible exploration range is still about 80 ms in time. The sought water protective layer is located at 65 ms, which corresponds to a distance of 120 m from the base of the pit. Additional extensive layers, which also contribute to the thickness of the protective layer, are the halite region, anhydrite and sandstone layers.

Exploration example 4 (Figure 8)

The objective of this exploration was to delimit clefted zones from non-clefted or less clefted zones. As is evident from Figure 8, minimal data processing was needed to obtain this information. The limits of the clefted region could be determined very accurately based on a simple investigation of the range. In this regard, a study frequency of 50 kHz was selected.

Exploration example 5 (Figures 9 and 10)

Due to many years ingress of water--for about 50 years--through the shaft tubes of an abandoned salt mine, some cavitation has formed in its bottom region, so that a latent hazard had developed due to potential rupture of the shaft lining, with effects on the above-ground surface. For the planned sonar exploration of the leached zone we dropped 4 gently rising holes of 80 m length from the shaft tube, about 10 m above the bottom region. Figure 10 also shows one measurement example for the time plot. The end of the leaching zone was determined precisely in the 4 drill holes and the magnitude is shaded in the form of a leaching zone in Figure 10. In Figure 9 we see the used measuring system including the bore hole probe just going into the drill hole.

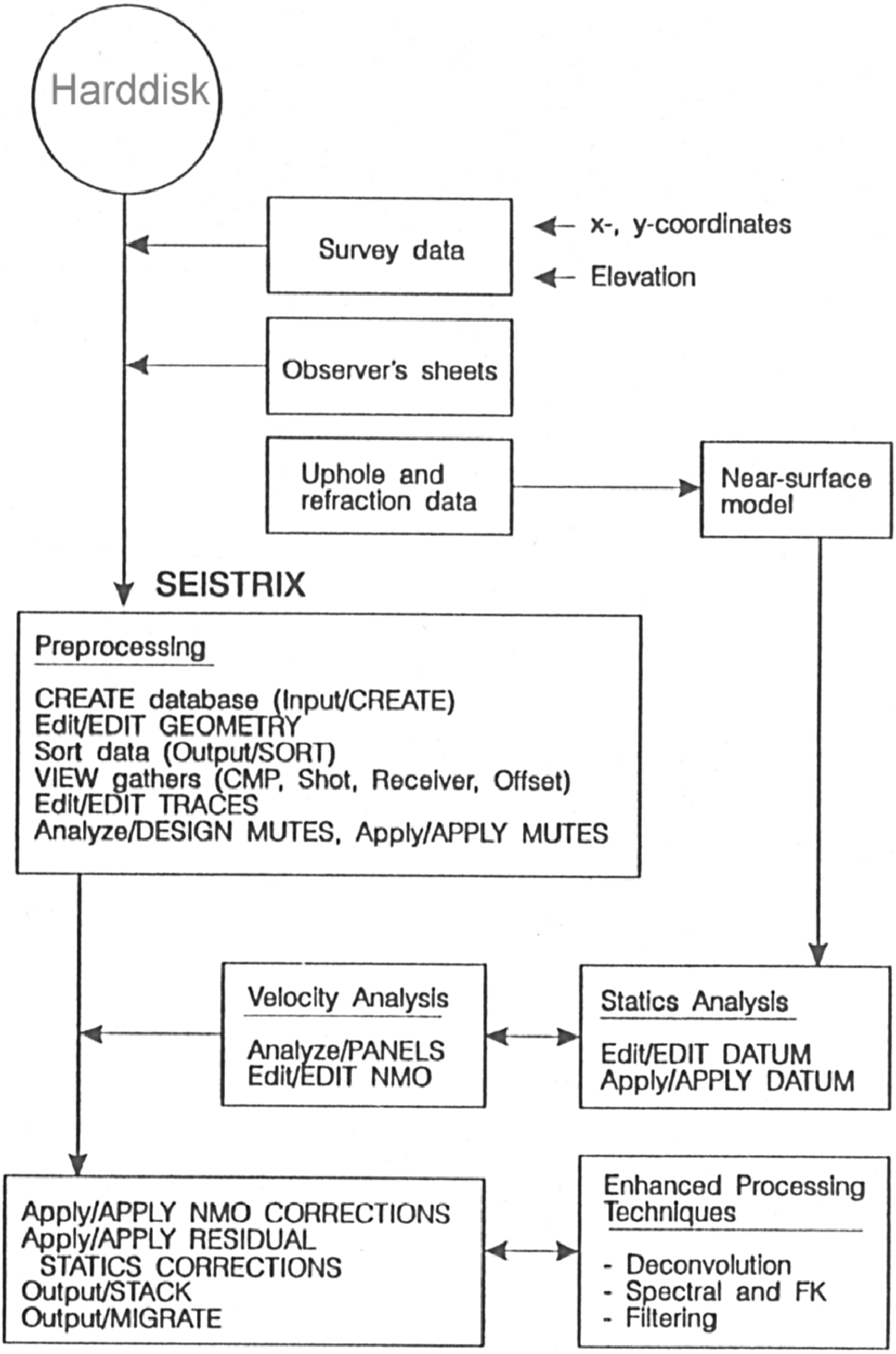
Exploration example 6 (Figure 11)

Between two abandoned salt mines there is a safety pillar of about 100 m thickness. The bottom region of the workings denoted as salt mine 1 is standing under non-saturated lye. In order to be able to estimate the potential hydrologic hazard of the salt mine denoted as workings 2, back in 1984 we began taking ultrasonic seismic measurements twice each year of the so-called penetration course. In the course of the following years it was clearly demonstrated that the leaching was progressive. It moved about 20 m from 1984 to 1995. This progressive leaching caused the mine operators to plan and set up a retaining dam.

List of figures for the exploration examples

Exploration examples 1 - 6:

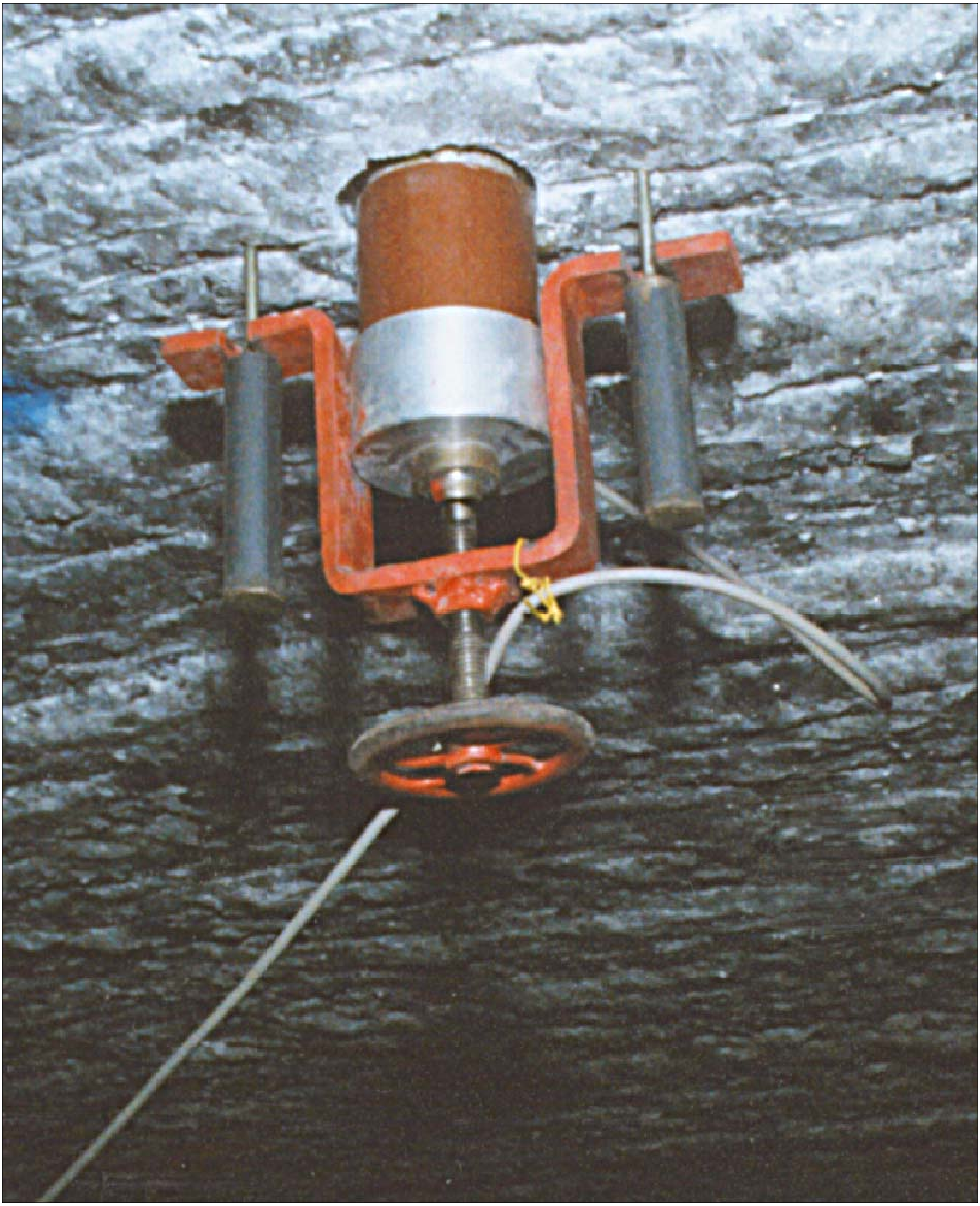
Figure 1



Seismic processing steps for sonar measurement

Figure 2

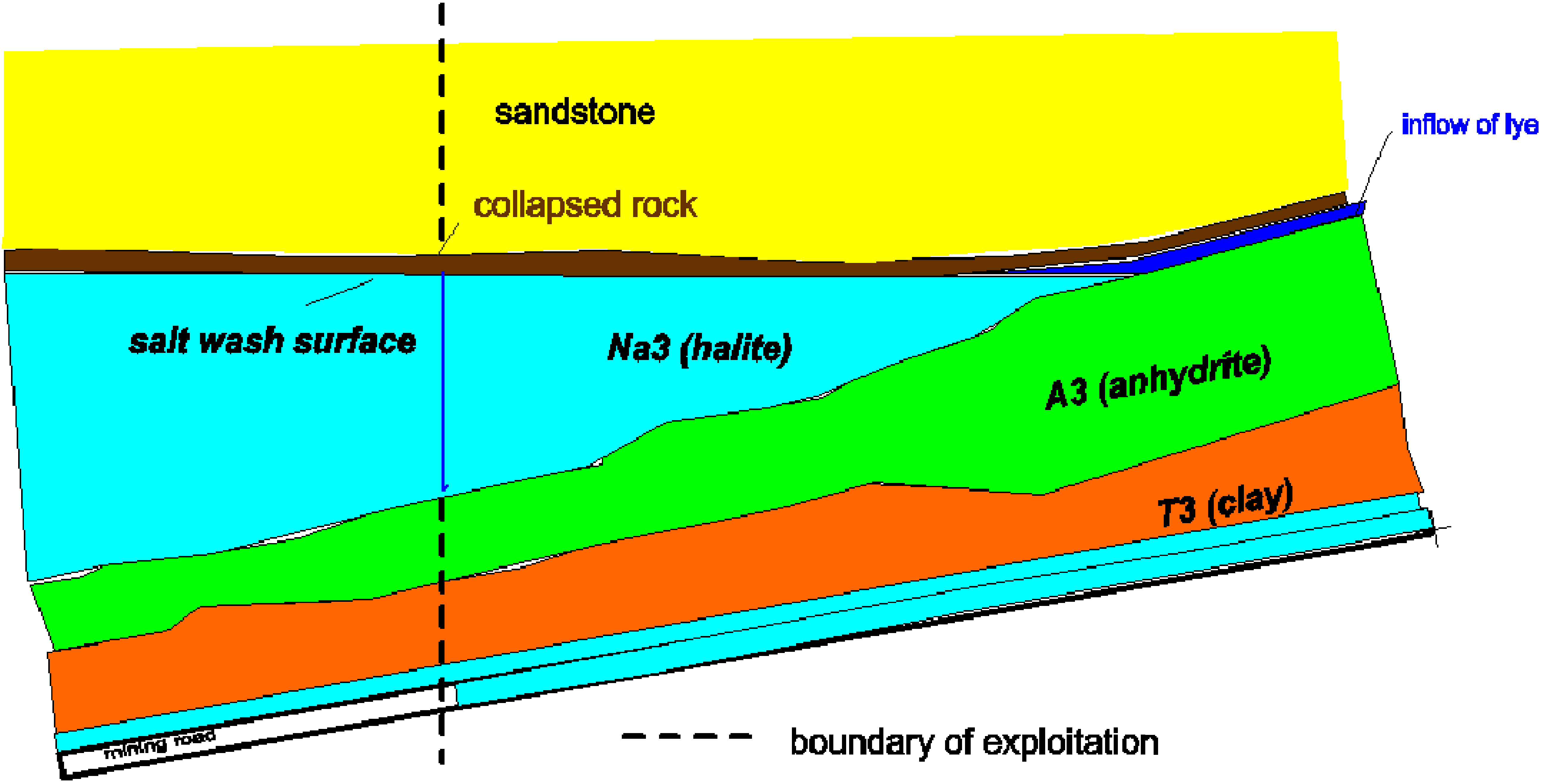
The ultrasonic-seismic measuring system KUTEC 4 with transmitter, receiver and borehole probe



Transmitter coupled to the salt rock

Figure 4

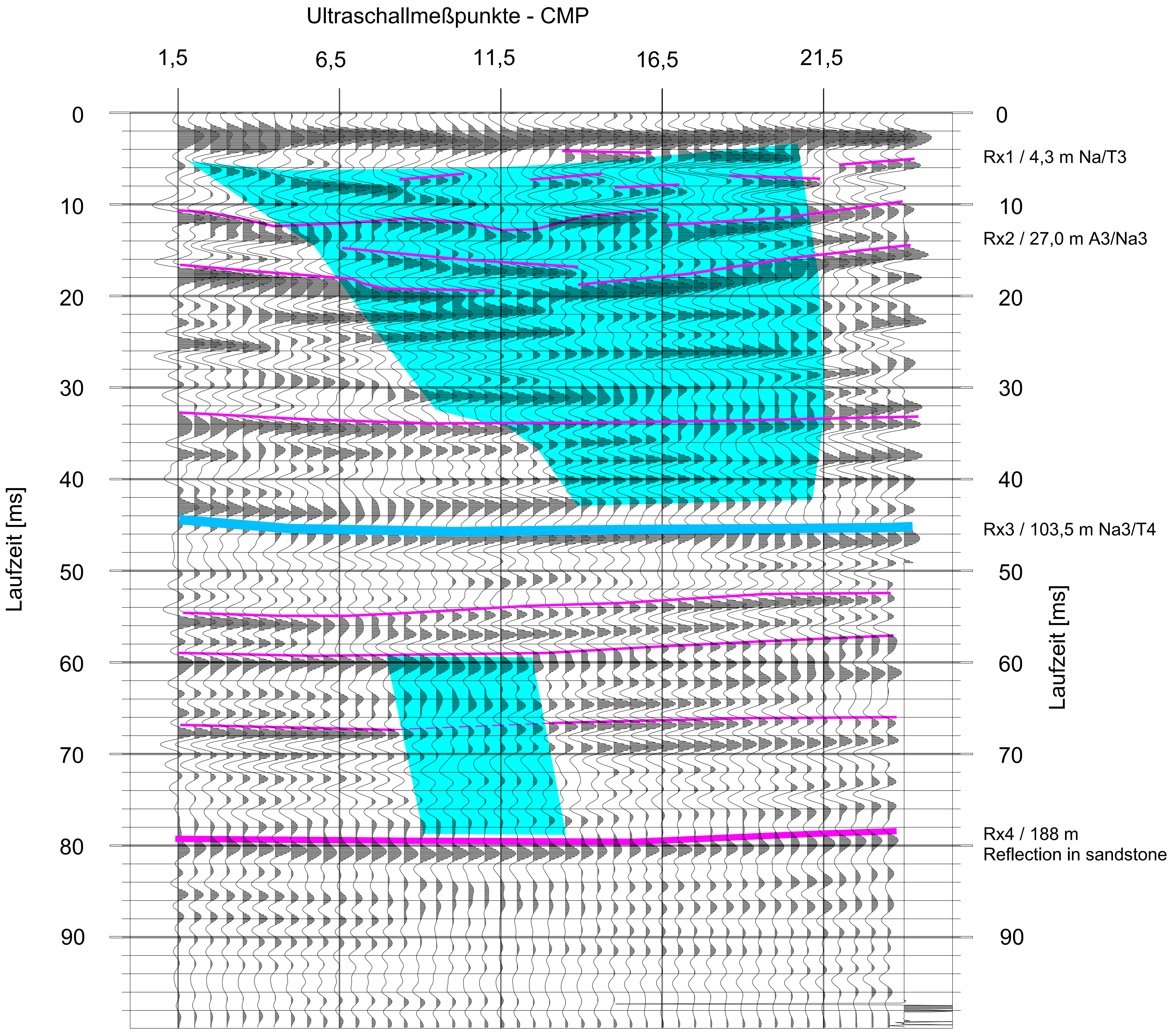
The thickness of Na3 can decrease to zero meters



Geological model

Leine-halite (Na3) as protective layer
against inflow of lye from the roof hanging

Figure 5



Legend:

Rx1... - seismic reflection

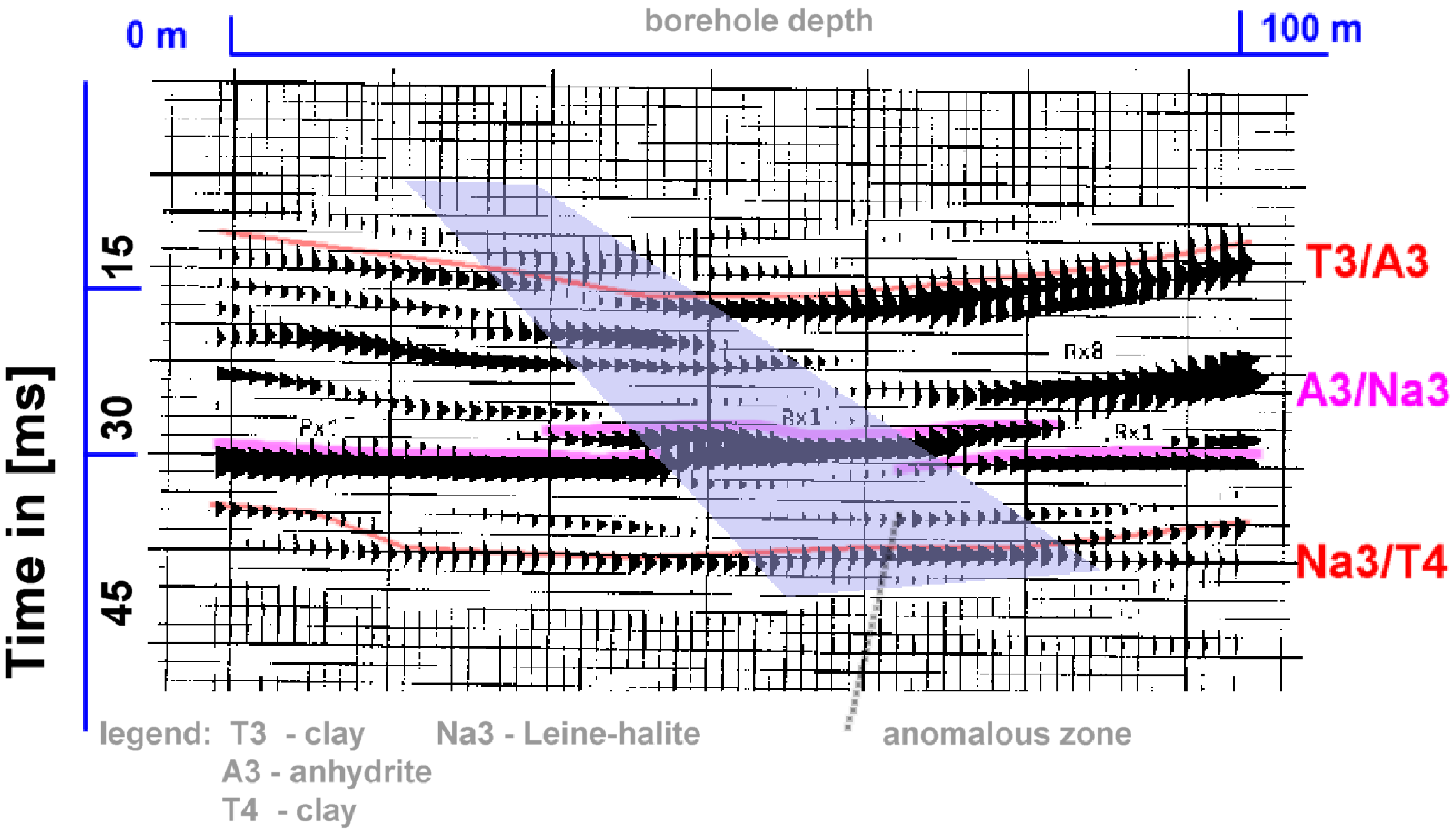
T3 - clay
A3 - anhydrite
Na3 - Leine-halite

CMP - common mid point

▬ - water protective layer
▬ - Rx-Reflection
🟦 - anomaly (cracks)

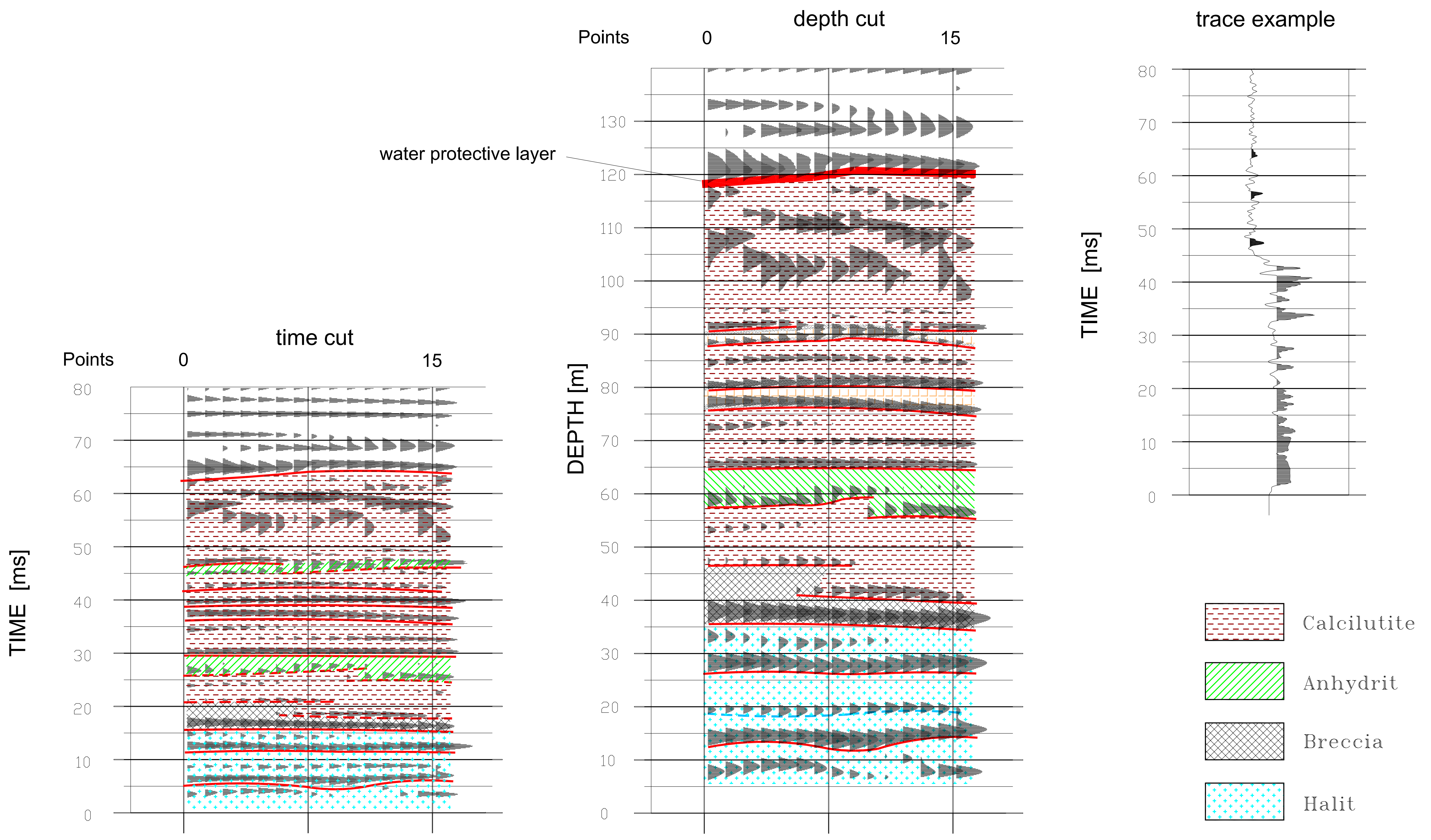
Ultrasound seismic investigation of the
hanging layer in a salt mine
Thickness of the water protective layer: 76,5 m (103,5 m - 27,0 m)
frequency: 20 kHz

Figure 6



Ultrasonic - seismic
Result of a borehole measurement (time cut)

Figure 7



Ultrasonic seismic measurement to the exploration
of the water protective layer

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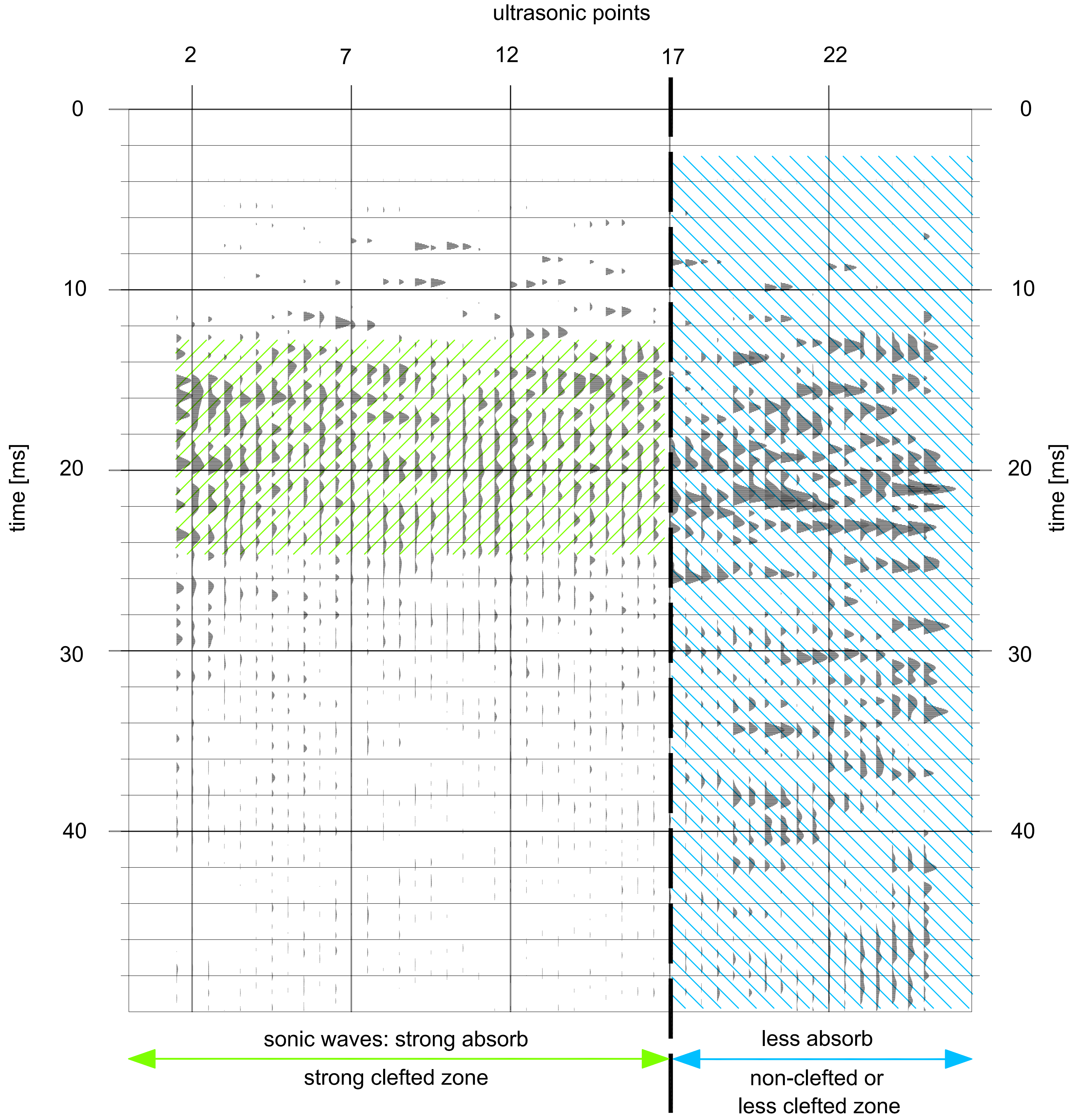

Ultrasonic measurement

Seismic timecut
frequency: 50 kHz

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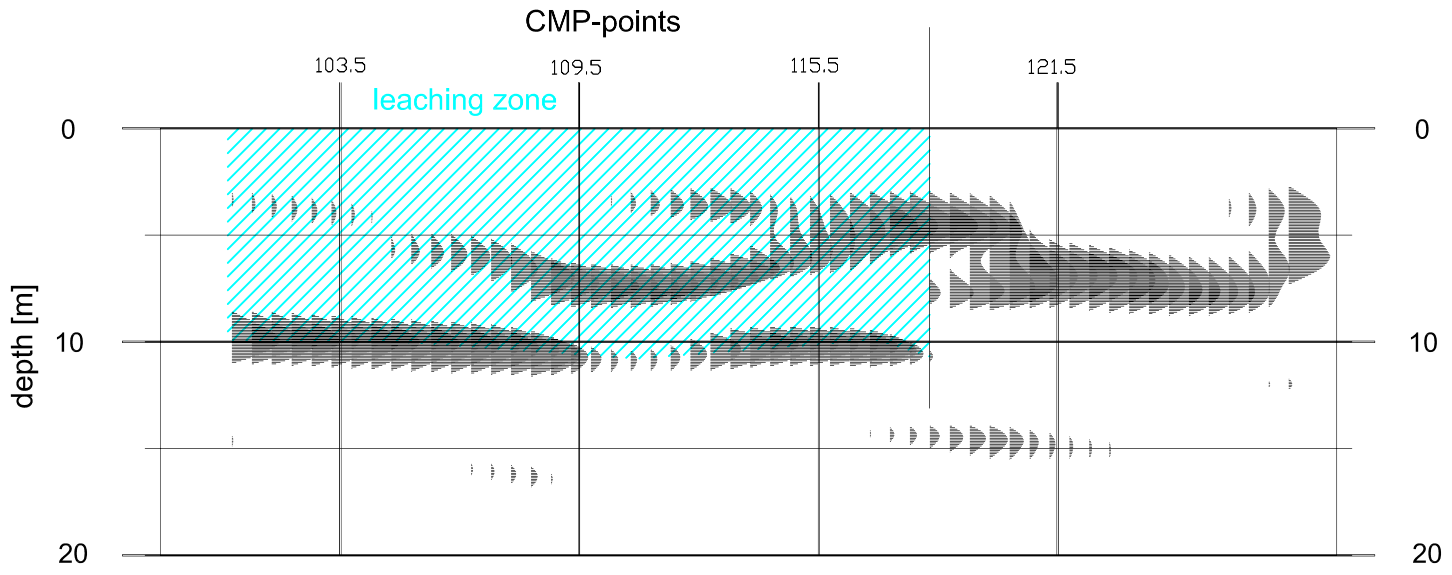
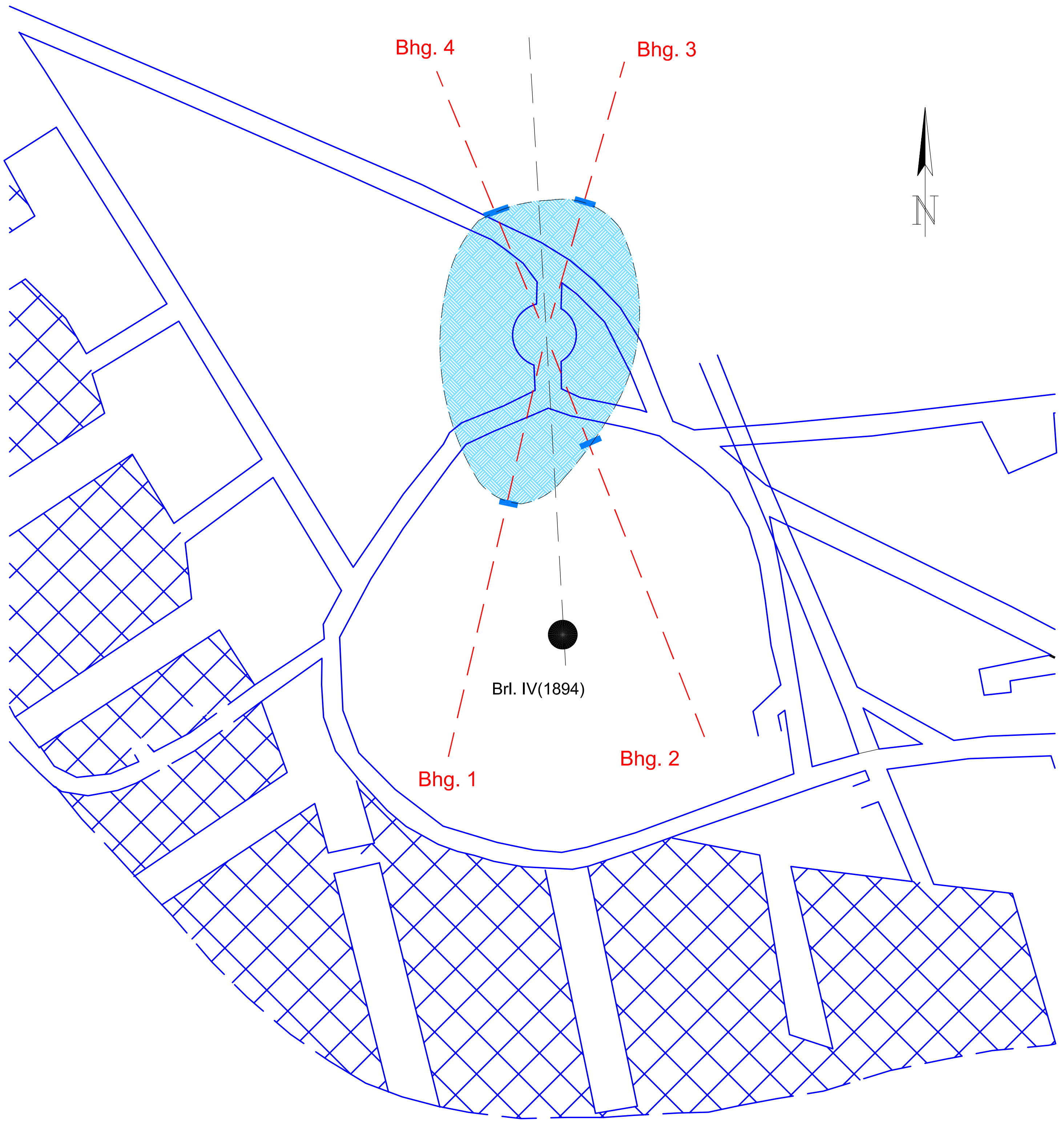
Ultrasonic borehole probe and the equipment in use

Figure 10





Legend:

━ - Boundries of Leaching, determined by borehole measurements (Sonar)

▨ - leaching zone, determined by borehole measurements

Ultrasonic borehole seismic measurement

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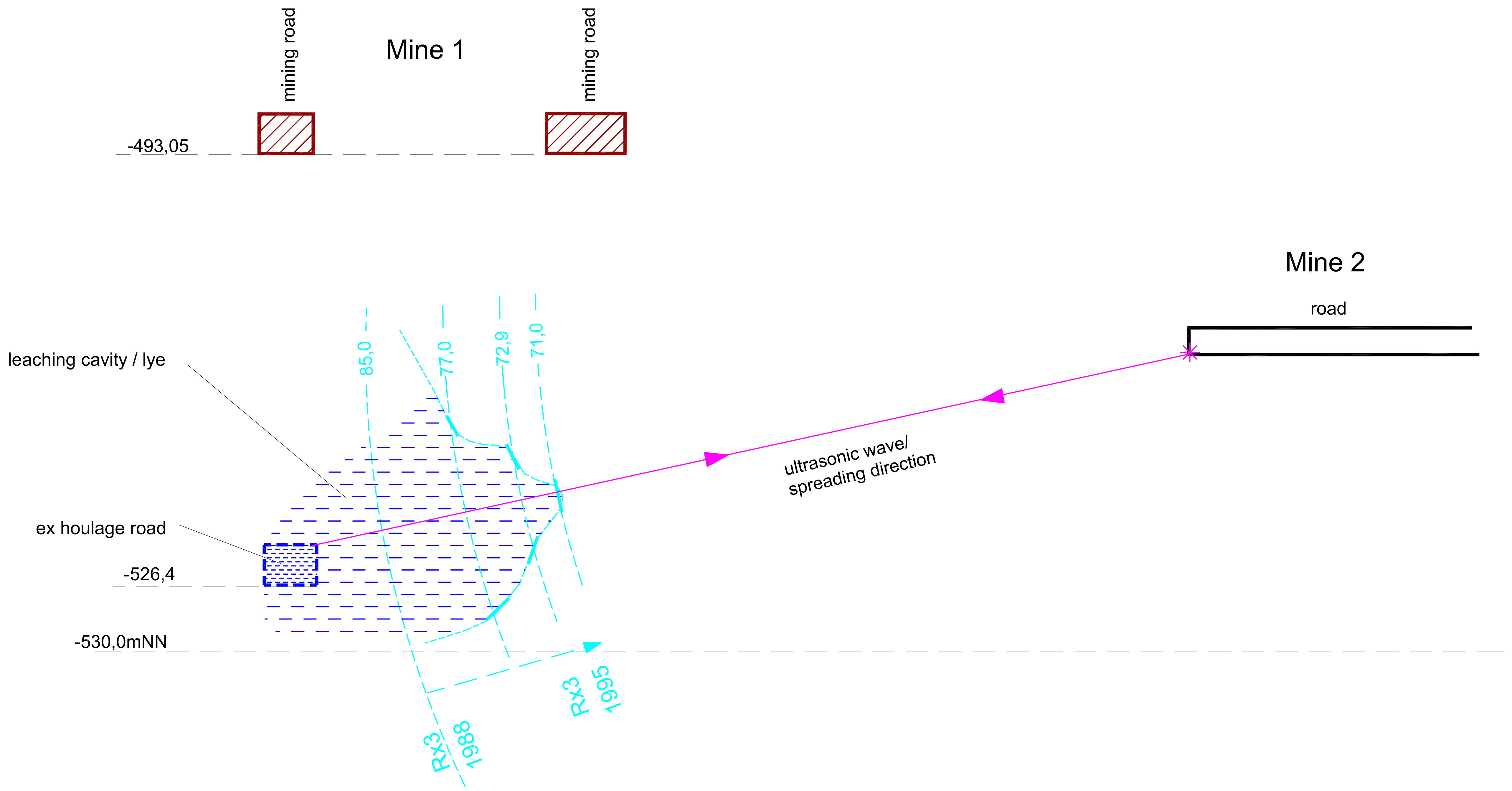

Ultrasonic exploration of a leaching cavity over a period of time (10 years)

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K-UTEC has for many years extensive experience with borehole radar investigations applied to geotechnical, environmental and mining problems and provide also many other geological and geophysical services.[1]

BOREHOLE RADAR MEASUREMENTS

TECHNICAL NOTE

I. PRINCIPLES OF THE METHOD

Dipole reflection mode

Dipole transmitter and receiver antennas are lowered in the same borehole and displaced stepwise along the measured interval. For each position, an electromagnetic impulse (central frequency 22 MHz or 60 MHz) is generated by the transmitter antenna. Discontinuities in the rock or soil around the borehole, like contacts between layers, voids, fractures, reflect part of the impulse, back to the receiver. The resulting signals are displayed in a way similar to reflection seismics, giving an image of the surrounding rockmass.

The investigation range mainly depends upon the electrical resistivity. It may be estimated as follows:

- a few meters or even less in clayey or silty ground: in most cases the method cannot be applied under such circumstances;
- 10 to 40 meters in normally fractured rock;
- 40 to 150 meters in massive rock;
- up to 300 meters and more in some exceptional situations (pure rock salt, very massive limestone or granite, ice, ...).

Directional reflection mode

The principle is similar to the dipole reflection mode, but the receiver consists of four antennas oriented in four different directions. In this way, the direction to a reflector may be determined, allowing full 3D imaging around the borehole.

Tomographic mode

In the tomographic mode, the transmitter and receiver antennas are lowered in two seperate boreholes. The signals transmitted through the rockmass or soil between the holes are recorded for every position of the transmitter and the receiver. The very large number of signals ("rays") thus obtained is processed numerically in order to compute a continuous image (tomogram) of radar velocity or radar attenuation in the investigated area. Using these parameters, it is possible to determine water content and resistivity.

The range in the tomographic mode is better than in the reflection mode : even in conductive ground, ranges up to 20 meters have been achieved.

II. EQUIPMENT

The equipment being currently used is the RAMAC borehole radar system with 22 MHz and 60 MHz antennas for the dipole mode and a 60 MHz directional receiver. Detailed technical specifications are available on demand.

III. BOREHOLE SPECIFICATIONS

Measurements are normally carried out in boreholes with a PVC casing of minimal inner diameter 60 mm (probe diameter is 50 mm). Measurement in open boreholes is also possible, provided the client guarantees the stability of the hole. Presence of water is no problem.
Due to the length of the probe, the borehole should be 3 to 5 meters deeper than the interval to investigate.

It is recommended to avoid using conductive fluids (mud or brine) during the drilling.

IV. SELECTED EXAMPLES

The first two examples described hereafter were acquired during an extensive site investigation campaign on the route of the new HST railway link through Belgium. The third example demonstrate the possibilities of high frequency electromagnetic tomographic methods for localisation of karsifications and other natural or man made voids and cavities. The last and fourth example described a geological investigation in a rock salt mine in Germany. We thank the engineering company TUCRAIL SA and the SOLVAY rock salt mine Borth for allowing us to use these results.

Viaduct foundation on karstified limestone (enclosure 1)

The 2 km long viaduct requiered the construction of 40 piers with a spacing of approximately 50 m. Preliminary boreholes along the viaduct axis had shown that the subsurface of the site consisted of strongly karstified limestone. Due to the total lack of correlation between boreholes, it was impossible to obtain a realistic image of the foundation ground using conventional techniques.

On each of the 40 piers of the viaduct, two boreholes have been drilled to a depth of 20 to 45 metres according to local conditions. Spacing between boreholes ranges from 12 to 24 meters. A systematic radar tomography campaign has been carried out on each borehole pair.

On the left tomogram of the radar velocity distribution (part a) of fig. A)) blue areas represent high radar velocities (massive, unkarstified limestone) while red represent low velocities (karstified areas with silty sand filling material). The transition from blue to red is progressive, showing the increase in fracturation or carstification. For each velocity it is possible to calculate the proportion of limestone versus filling material. The central part b) of figure A) shows the calculated geological model of the investigated area between the two boreholes on the base of primary radar velocity distribution. The attenuation tomogram (c))on the right side of the figure A) is displayed with a resistivity scale, the distribution being similar to those on the velocity tomogram on the left. It is interesting to note that although resistivities are low, the radar tomography technique still works.

Additional with the geophysical tomographic data correlations between these parameters (velocity and resistivity) with geomechanical presiometric tests in the boreholes (Youngs modulus and pressure level) has been made. The diagram in figure B) shows the result of a correlation of geomechanical and geophysical data of one tomographic measurement of a pear. In most cases the various curves correlate well. The advantage of such a correlation lies in the information gain of the extrapolation of the results on local point presiometric measurements to a plane by using geophysical crosshole data.

All the overall tomographic and geomechanic results were used for the calculation of the foundations and the grouting campaign realised before construction works.

Railway tunnel investigation (enclosure 2)

The tunnel project is a part of the high speed railway link between Paris (France) and Colongne (Germany) over Brussels (Belgium) and lies near Liege (Belgium). It is 6 km long and the major part of the tunnel will intersect Carboniferous shales and sandstones with coal measures and old mining works. In the central part of the tunnel, carboniferous limestone will be intersect for about 700 metres.

Borehole radar reflection measurements were realized in nearly all boreholes intersecting the limestone, and gave detailed information about the rockmass surrounding the boreholes, within an investigation radius of about 50 metres.

A schematic cross-section of the eastern contact between the limestone and the shale is shown in the enclosure 2. The geological interpretation is a result of the two borehole radar reflection measurements (boreholes 40 and 41). The tunnel is very shallow (10 m - 30 m) along this section, due to the presence of a valley. The limestone-shale contact is regionally known for ist strong karstification, resulting in numerous sinkholes, some of them reaching the surface. The shallow sinkholes are filled with loose topsoil while deeper sinkholes are filled with collapsed shale. Identifying such carstic problems was an imprtant task of the geological-geotechnical investigation programme.

The measurements reported in the case study were carried out in the reflection mode, using the Swedish RAMAC borehole radar system with 60 MHz dipole and antennas. The two upper radargams show the raw data recorded in boreholes 40 and 41 ; on the two lower radar sections, the most prominent reflectors are indicated and annotated. The lower part of the enclosure 2 contains the geological interpretation model as a result of the radar refelction measurements described hereafter.

In the borehole 40, two thin clay layers (stratigraphic marker beds) were intersected at depth of 32 and 45 metres ; they are clearly identified on the radar survey record (reflectors A and B). The intersection angles with the borehole can be readily determined (63^0 and 61^0). A prominent point reflector, characterized by a typical hyperbolic reflection (C) is also easily observed at a depth of 22 m and a distance of 10 m from the borehole. It is probably due to a karstic cavity.

In borehole 41, the clay layers were not intersected within the depth range of the borehole. However, the radar survey does show them (A and B) intersecting the continuitation of the borehole axis at depths of 62 and 75 m, i.e.,below the drilled interval. The reflectors are observed to a distance of at least 35 m, showing that the geological structure is regular and continuous (no faults or folds in the vicinity of the borehole). Borehole radar results strongly suggest the continuity of the marker layers corresponding to reflectors A and B between the boreholes, as shown on the under figure.

In the upper part of borehole 41, numerous reflectors are observed, but they do not display clear structure. The limestone is probably strongly fractured in this area.

Reflectors D, E and F seen from borehole 41 are obviously not related to the bedding. They are nearly vertical and located 50 metres away from the borehole. One possible interpretation is that they are due to the limit of a sinkhole, located 50 metres away (below figure of the geological interpretation). Two contol boreholes were drilled in that area, confirming this interpretation and providing important information for the planning of the tunnel works.

Cavitiy localisation (enclosure 3)

About 80 m away from the railway link Mühlhausen - Heiligenstadt a sinkhole of a dimension 20 m x 7 m was falling down. A sketch of the measuring situation is include into the enclosure, fig. d). The geological and tectonical knowledge of this area proves that in lengthening from North to South geotectonical faults and so an endangering of the railway link was very probable.

Three boreholes both sides of the rail were drilled to near 60 m depth. Between these boreholes electromagnetic tomographic measurements were carried out to localize the carstic cavities or the level of carstification near the rail. The example present the geophysical result and the geological interpretation model of the crosshole tomographic measurement between the boreholes 1 and 2.

The limestone of the investigated area is from the stratigraphical point of view a rock of the Upper and Middle shelly limestone. Especially the limestones of the upper and middle part of the Middle shelly limestone are normaly high karstified. The base of the Upper shelly limestone is a very compact limestone layer without clay content (crinoidal limestone) and with a thickness of around 10 meters.

The velocity (fig. a)) and the resistivity tomogram (fig. c)) shows a three-piece structure. In around 40 meter depth the velocity distribution shows the boundery plane between the base of the Upper shelly limestone (crinoidal limestone with velocities of around 90 m/µs) and the high carstified Middle Shelly Limestone (approximate 60 m/µs to 80 m/µs). The crinoidal limestone is around 12 meters thick. Above this layer the badded rocks of the Middle shelly limestone (interstratification of limestone and clay stone layers) with low karstification are visible. Fig. b) of enclosure 3 shows the geological situation with the stratigraphic bounderies from the borehole cores and the geophysical interpetation of the tomographic measurements.

Important for an assessment of the endangering of the surface near the rail is the fact, that the crinoidal limestone is in the central part between the boreholes strong disordered, high karstificated and loose (velocities around 80 m/µs and less). Only near the boreholes the velocities reach normal values of unkarstified limestone (90 m/µs to 100 m/µs). The geophysical results demostrate a permanent endangering of the surface and the rail.

Parallel seismic tomographic measurements confirmed the detected loose and high karstified zone within the crinoidal limestone.

After the geophysical investigations boreholes were drilled into the dangerous zone. Several thousend tons of fluid concrete were filled into the karstified area to stabilize the surface.

Geological exploration in a rock salt mine (enclosure 4)

The knowledge of the the exact bedding of the hanging clay back, a very thin clay layer of only several millimetres thickness, is very important for the fist mining phase, the TBM or blasting heading excavation of the head drift. For the planning of the maximum possible excavation height of the chamber during the second mining phase the knowledge of the structural conditions of the lying anhydrite is decisive.

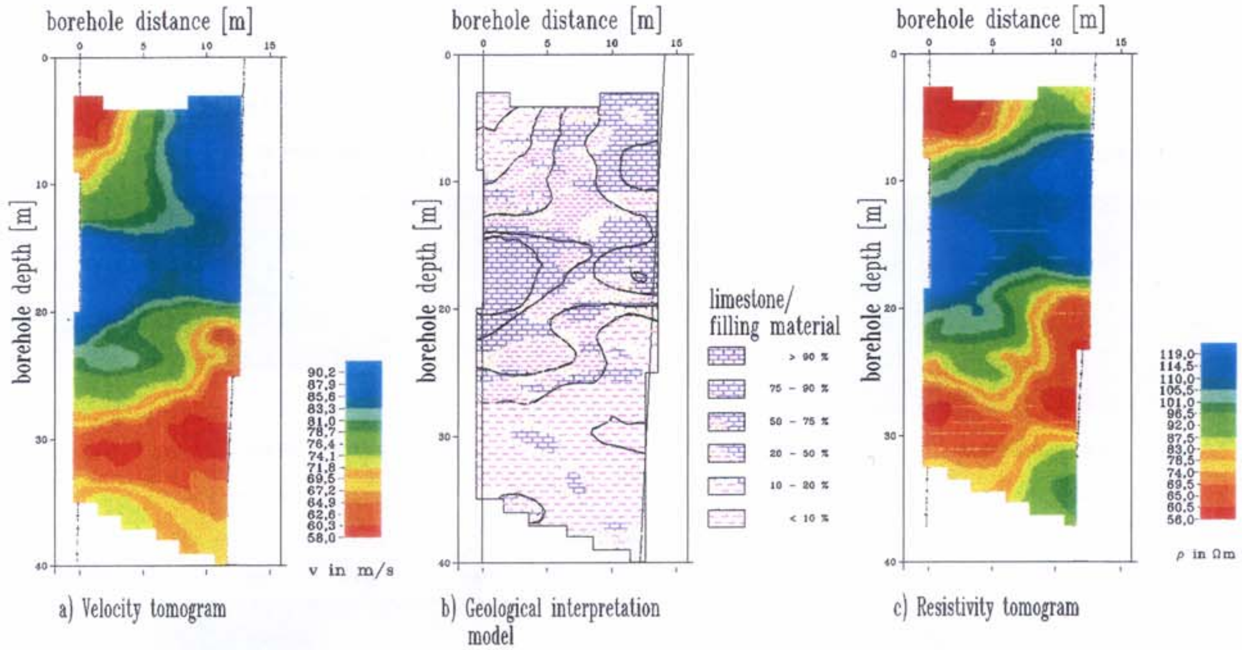
The exploration of new mining areas is carried out by drilling long horizontal boreholes (length up to 600 meters) ahead of existing mining drifts. Dipole and directional radar measurements realised inside these boreholes provide a detailed image of the deposit with an investigation radius of at least 50 to 100 meters.

Since 1990 more than 50 boreholes were measured with the described borehole radar technique. The following representative example of enclosure 4 (upper part a) --> radar section; lower part b) --> geological interpretation model) shall show the efficiency of the method for the preliminary geological exploration of salt deposit from measurements in a 400 metres long horizontal borehole. Several major reflectors are clearly identified:

- The reflectors A and B correspond to thin clay backs located above the borehole axis. The reflection B comes from the main clay back (very important for the planning of the drift).
- Reflector C correlates with the contact between the salt and the massive anhydrite in the lying wall. This contact is uneven with local uplifts.
- The reflector E correspond to two previous boreholes. One of them exposed the lying anhydrite.

In the first 90 m the borehole was free of brine. The other main part of the hole was filled with brine resulting from the drilling process. Normally borehole radar measurements are impossible in high conductive borehole fluid medium. The example shows, that measurements under special conditions (small borehole diameter in comparision with the probe diameter, surrounding rocks with very high resistivities) in brine filled boreholes are possible. The differences in the amplitudes between the measurement in brine and in air show the high attenuation of the primary electromagnetic energy by the brine. But the main reflectors are important for the geological interpretation and sure to determine.

All borehole radar investigations in the Borth mine were carried out with the 60 MHz-dipole antenna. The geological correlation of the reflections to the hanging and lying wall is possible and is well defined. Several parallel surveys with the directional antenna confirmed this statement.



a) Velocity tomogram

b) Geological interpretation model

c) Resistivity tomogram

Fig. A: Tomographic results and geological interpretation of one future pier

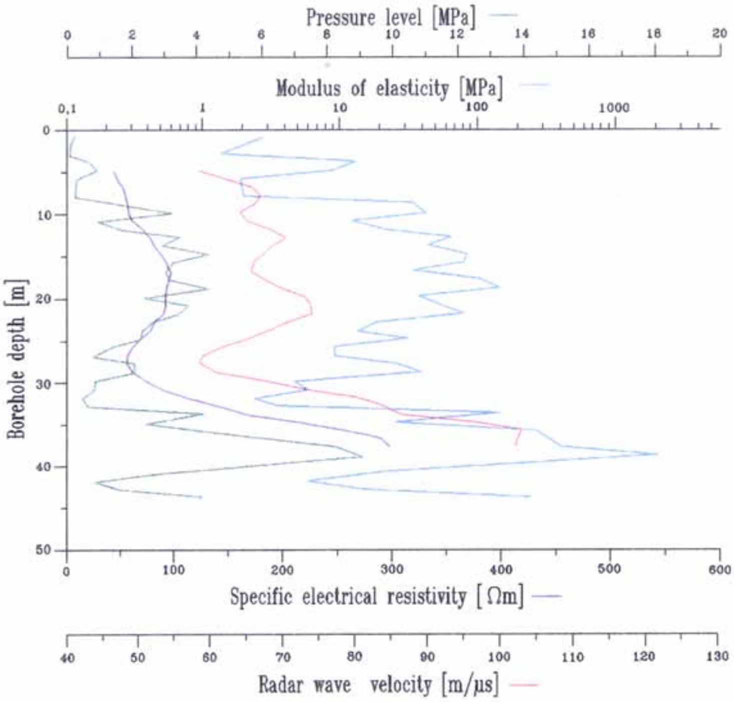
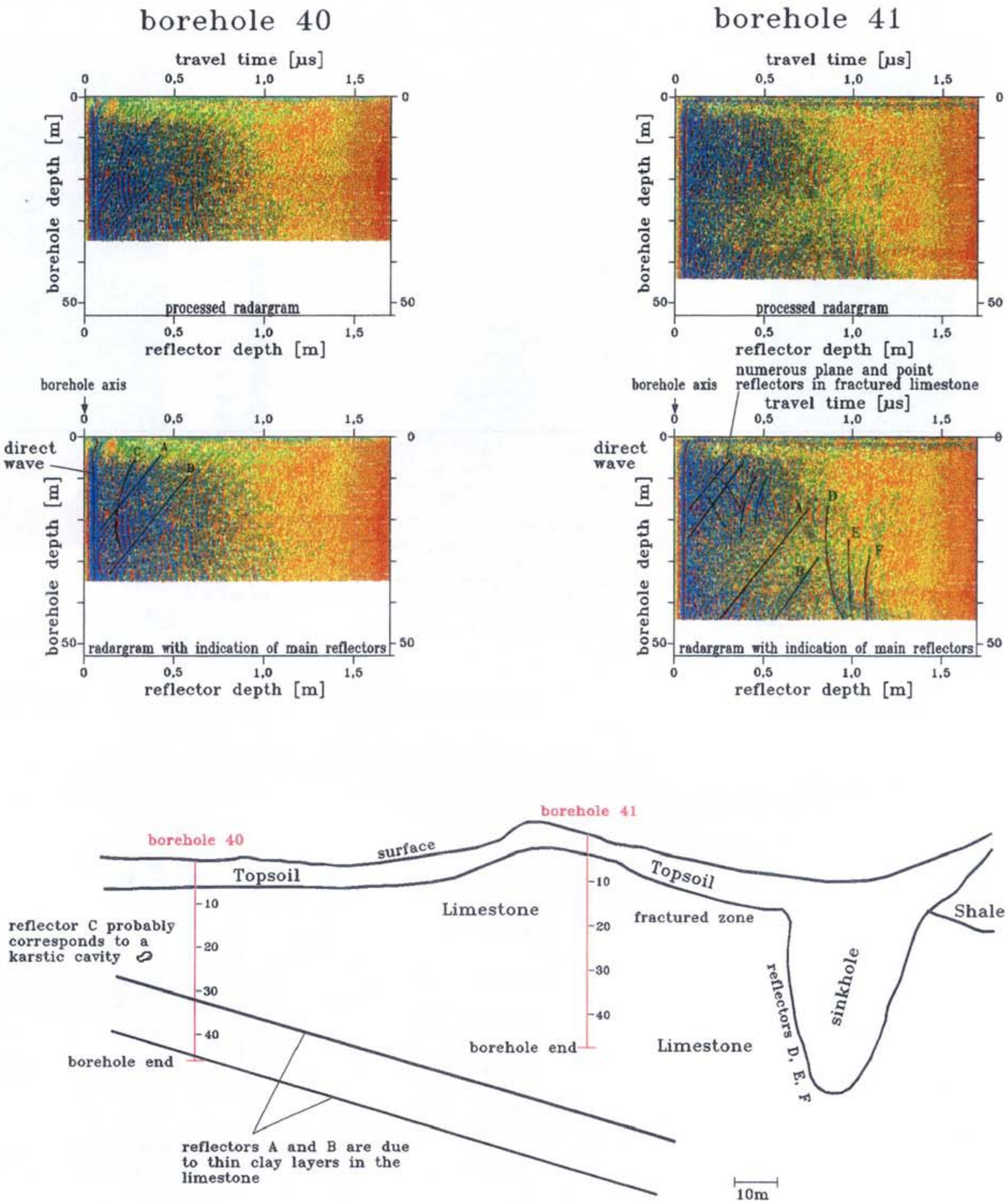


Fig. B: Correlation and extrapolation of selected geomechanical measurements, which are made at certain points, into the plane between the boreholes

Investigation of rock karstification in order to give a valuation of the endangering degree of a brigde foundation project in Belgium



Investigation of the geological structure from boreholes along the planned tunnel axis of a HST–tunnel in carboniferous surroundings in Belgium

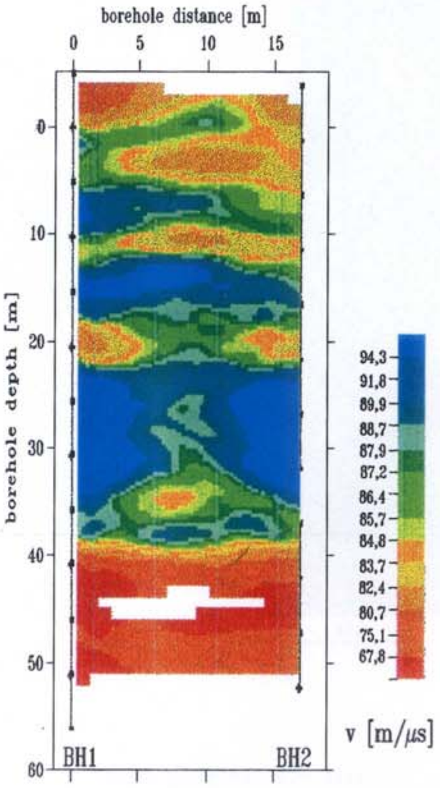


Fig. a) Velocity tomogram

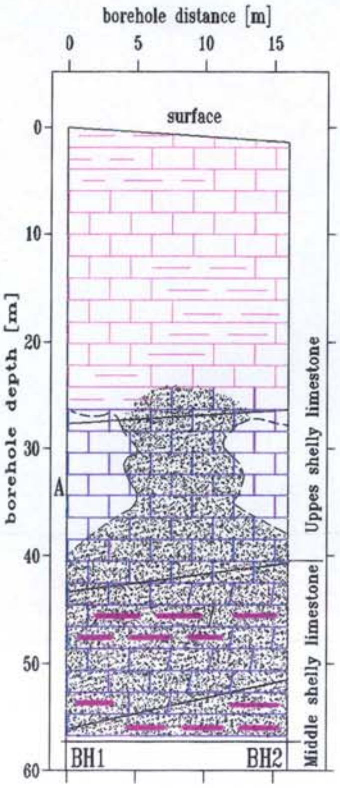


Fig. b) Geological interpretation model

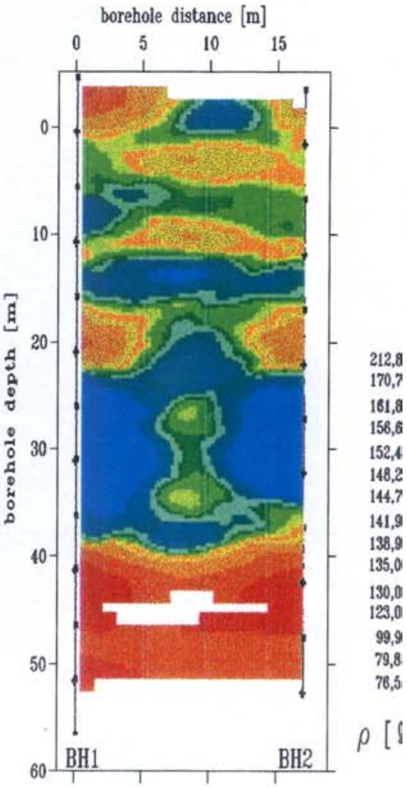
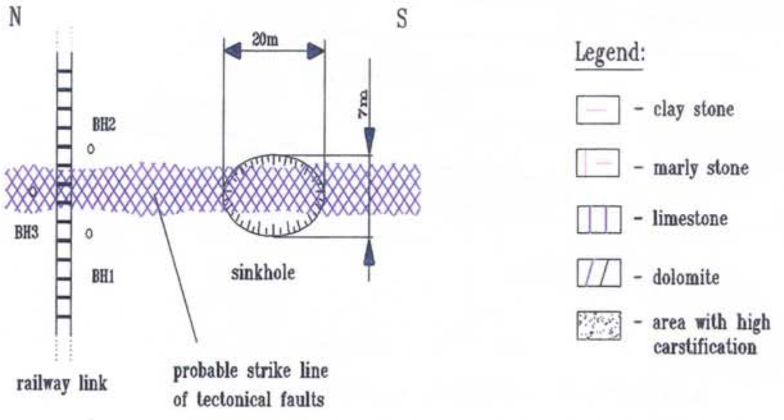
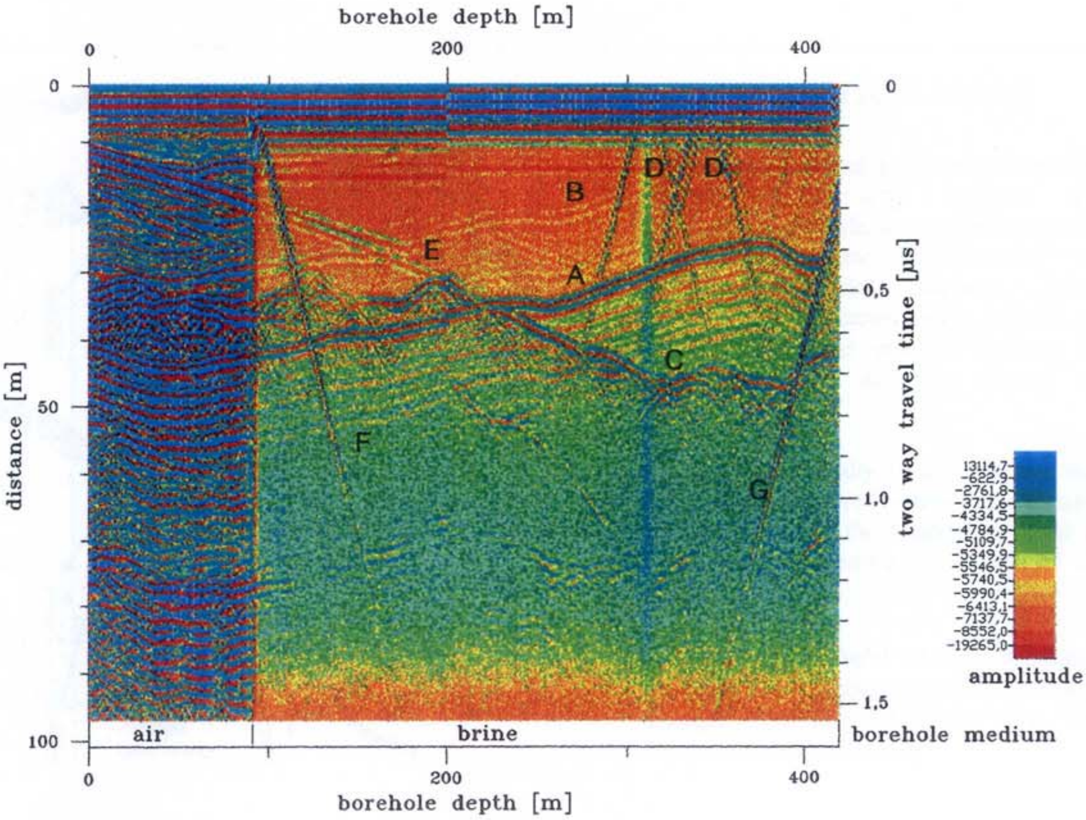


Fig. c) Resisitivity tomogram

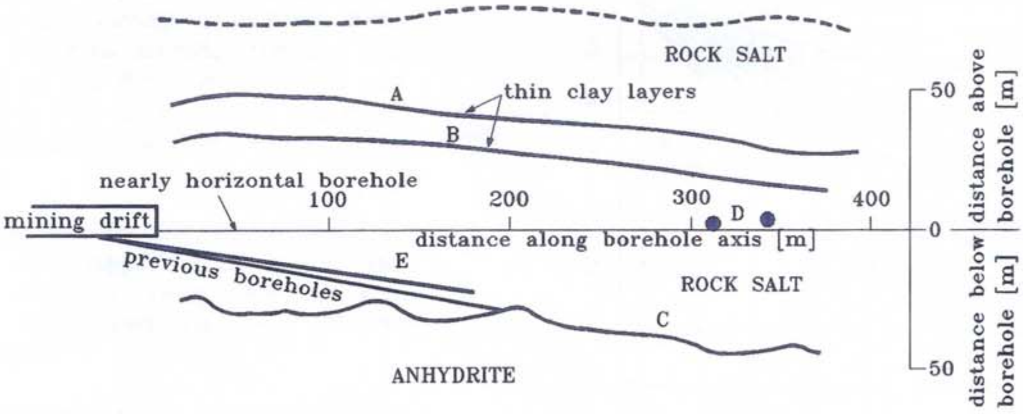


. d) Sketch of the measuring situation

Crosshole radar tomographic results for localisation and assessment of carstification near a sinkhole for a high speed railway link



a) Radar section



legend:

D - local anhydrite interbedding

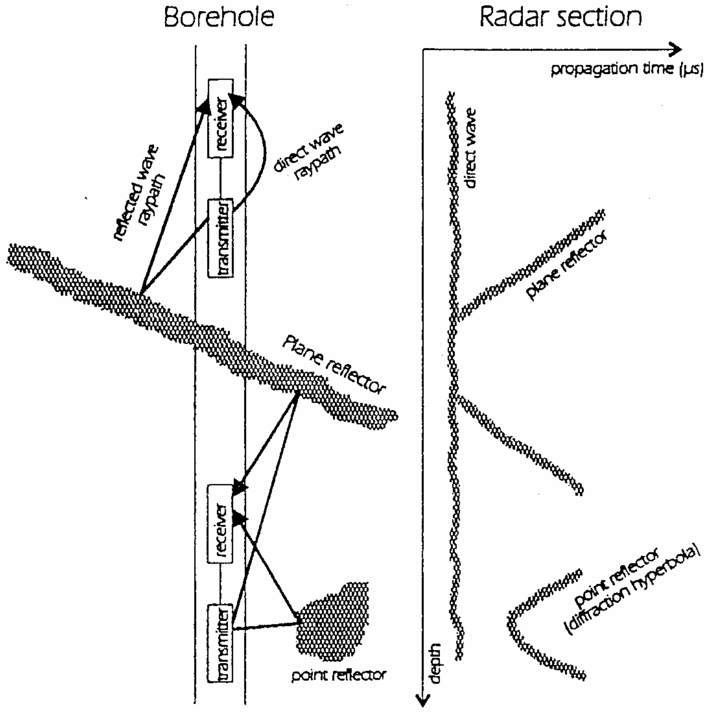
F - reflection on brine mirrow of the borehole

G - reflection on metal bolt

b) Geological interpretation model

Radar section (a) and geological interpretation profile (b) of a radar reflection measurement in a horizontal borehole in the Borth rock salt mine (FRG)

K-UTEC uses the RAMAC borehole radar. Several antennas are availabie: dipole 22 MHz, dipole 60 MHz and directional 60 MHz. The system may be used in the reflection mode or in the tomographic mode:



REFLECTION MODE

Both transmitter and receiver antennas are located in the same borehole. The transmitter sends electromagnetic impulses into the ground. Reflections on discontinuities like fractures, joints, cavities, ... are detected by the receiver and displayed as radar sections showing the structure of the rockmass around the borehole.

Penetration is usually 10 to 50 m, but may reach several hundred meters in some cases. In clay or shale, the method may not be used due to excessive attenuation of the signals.

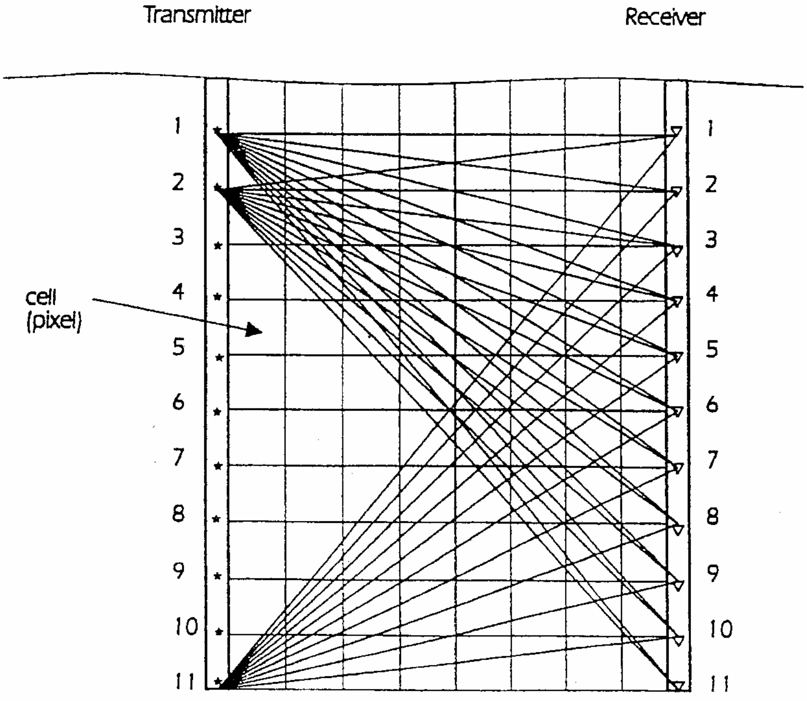
The method is useful to map geological structures or detect fractures, lithology changes, cavities which were not intersected during drilling.

TOMOGRAPHIC MODE

The transmitter and receiver antennas are located in two separate boreholes. The electromagnetic impulses generated by the transmitter travel through the rockmass to the receiver. For each raypath, traveltime and amplitude of the signal are measured and processed in order to obtain radar velocity or radar attenuation sections between the boreholes.

From radar velocity and attenuation, it is possible to compute water content and effective resistivity. These parameters give valuable informations on rock or soil characteristics.

Radar tomography may be used to detect water content variations, changes in lithology, cavities, ... between two boreholes.



Field of Reference Applications

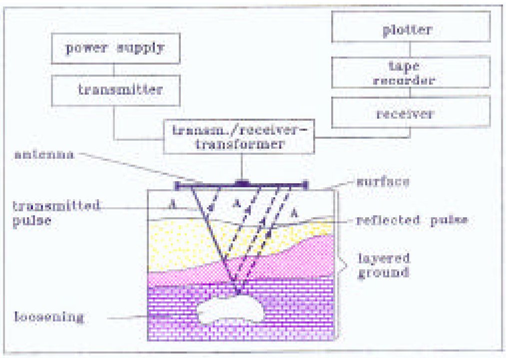
The following table contains a summary of the main applications of borehole radar surveys carried out by Kali-Umwelttechnik (K-UTEC, Germany).

Field of application	Description of main applications and investigation possibilities
Mining	→ Geological and geotechnical investigation of different mines, mainly in potash and rock-salt mines but also in diamond, gold, coal, uranium and talc mines; → Structural investigation in front of the mining face in long horizontal exploration boreholes; → Localization of brine filled or leaching areas especially in salt mines; → Structural investigation of salt cavern fields; → Localization of old man-made galleries in mines
Quarring	→ Geophysical exploration of new limestone quarries; → Detection of karstfield areas within new quarries, especially in limestone
Hydrogeology	→ Investigation of the fracture system within the rocks around boreholes for water production; → Mapping of the sedimentary structure of subsoil
Civil Engineering	→ Soil investigation for foundation of bridges and viaducts; → Geological and geotechnical investigations of tunnels;
	→ Investigation and localization of natural karstifications and man made cavities under buildings, railway causeways, bridges and son on, → Special soil investigation under old historical buildings; → Investigation and localization of cracks within dams
Environment	→ Geological and geotechnical investigation of new and still active waste deposits; → Investigation and monitoring of the fracture system in hard rock for nuclear waste storage; → Monitoring of tracer measurements; → Monitoring of in situ cleaning processes within high contaminated areas; → Investigation of an old nuclear power plant site

K-UTEC GmbH Sondershausen

Georadar

measurement principle

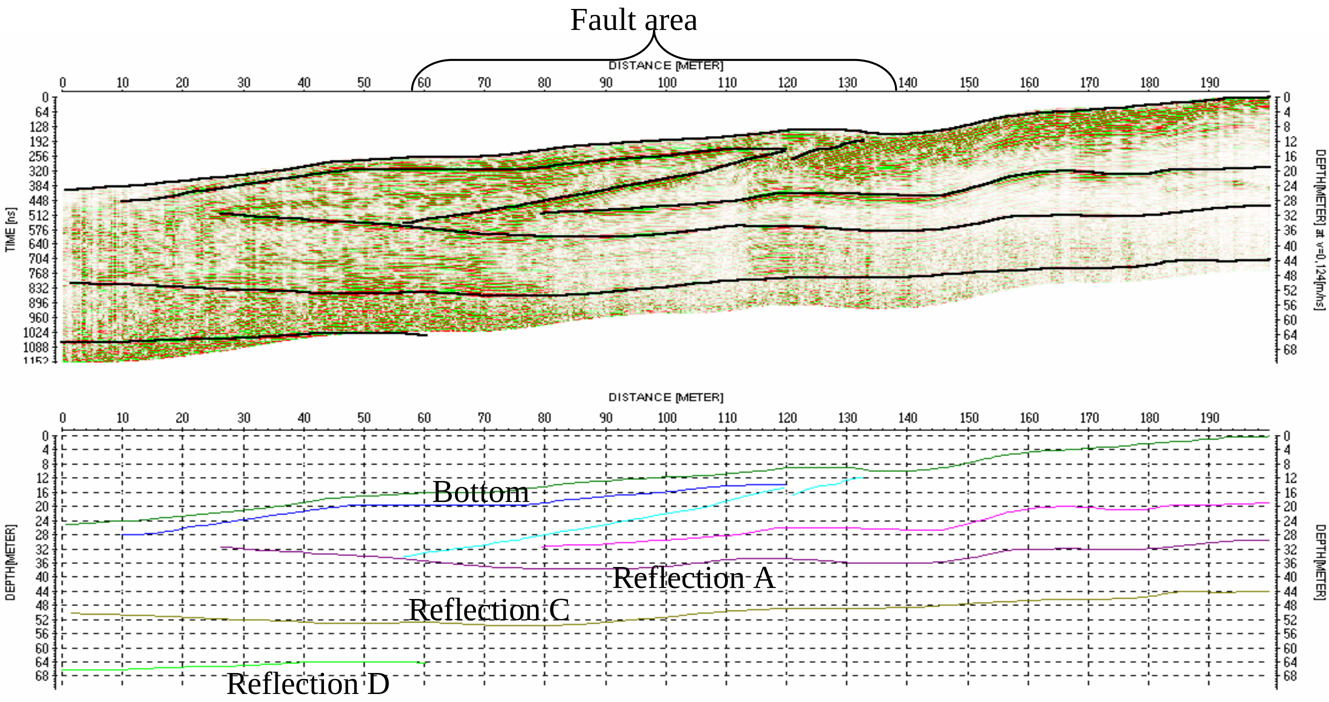


100 MHz GSSI – GPR-antenna

Applications

- Investigations of layer boundaries, that means layer structure in sediments and solid rocks
- Investigations of structures in sedimentary and solid rocks in the near surface area (weatherings, fracture structures)
- Soil examinations (differentiation of soil and/or geomechanical relevant complexes)
- Investigation of geogen and/or anthropogen caused anomaly areas (cavity caused by former mining and/or subrosion, intrusions in rocks, building fragments, archaeological objects)
- Investigation of hydrogeological circumstances (Investigations of aquifers and hydraulic relations)
- Investigations of sediments
- Investigations of routes, embankments, pipes and cables

Example:



Example of an investigation of layer structures

Kali-Umwelttechnik GmbH
Am Petersenschacht 7
99706 Sondershausen

Sondershausen
Abteilung Geophysik
E-mail: Geophysik@kutec.de

Tel: 03632 6100
Fax: 03632 61010
www.kutec.de