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CONTRIBUTION TO EXPERIMENTAL GEOMECHANICAL AND SEISMOLOGICAL MEASUREMENTS IN THE JERONÝM MINE

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ABSTRACT
Experimental geomechanical and seismological measurements are performed in the medieval Jeroným Mine near Čistá (Sokolov district). The main aim of this activity is geomechanical stability evaluation of this monument. Periodical monitoring was started in 2001 whereas quarterly period was applied (measurement of crack development in the mine working, development in changes in convergence cross-sections of linear and spatial workings and fluctuations of water levels in underground spaces). Seismological monitoring was started during reconstruction of partly impassable drainage adit. At present, selected parts of described geomechanical system are newly instrumented to obtain continuous information.
Data obtained from periodical and continuous monitoring are presented in this contribution. Interpretation of seismological data on both natural and technical seismicity and fluctuations of water levels is presented in details.

KEYWORDS: medieval Jeroným Mine, geomechanical monitoring, seismological monitoring

INTRODUCTION

Many historic workings exist in the area of the Slavkovský les Mountains that are connected by extraction of tin and tungsten ores. One of them, medieval Jeroným Mine in Čistá near Mariánské Lázně, Sokolov District, west part of Bohemia, presents the unique and significant example of mining works since the 16th century. In 1990, the Jeroným Mine was declared a cultural monument and there is an intention to make this mine accessible for the public as a historical mining museum (e.g. Žůrek and Kořínek, 2001/2002, 2004).

Jeroným Mine is comprised of a complex system of shallow underground galleries and wide openings in a number of levels located above each other, though, at present, the bottom part of the complex is flooded with water. Presently, two basic parts form the complex of historical openings – Old Mine Workings and Abandoned Mine Workings, which are separated from each other by a number of collapses (caved in rocks) of larger extent; both parts have their own entrances. The tin-wolfram deposit of Jeroným is adjacent to the southwestern margin of the Krudum massif. The deposit there is in granite and the ore mineralization has a form of endocontact bands of lenticular shape (e.g. Bernard et al., 1981).

The purpose of present geological, geomechanical, hydrogeological and seismological monitoring in the Jeroným Mine is evaluation of the geomechanical stability of the part of the Abandoned Mine Workings (e.g. Žůrek et al., 2005; Kaláb et al., 2006). First, it means the checking of current mining activities' impact on historical mining areas and on the road above the mine workings, as some of these are not situated very deep under the surface. Regular measurements for the geomechanical stability assessment of Jeroným Mine have been carried out since 2001 – primarily only quarterly measurements and since the year 2004 also some continual measurements.

Figure 1 presents sketch of Jeroným Mine (Abandoned Mine Workings) including two front views. Positions of instrumentations of distributed control and measurement system are also marked there. Knejzlík (2006) realizes detailed description of apparatuses of first stage of this system.

GEOLOGICAL MONITORING

Development of cracks in mine working has been quarterly observed at 10 measuring points by means of plaster and/or glass targets (example in Figure 2). Selected cracks were described in detail from the geological and structural viewpoint. Selection and documentation of points were made in 2001. Detailed structural-tectonic measurements were also performed. Some slight changes, i.e. new fissures

Fig. 2 Glass target on fissure in a rock pillar near Jeroným shaft.

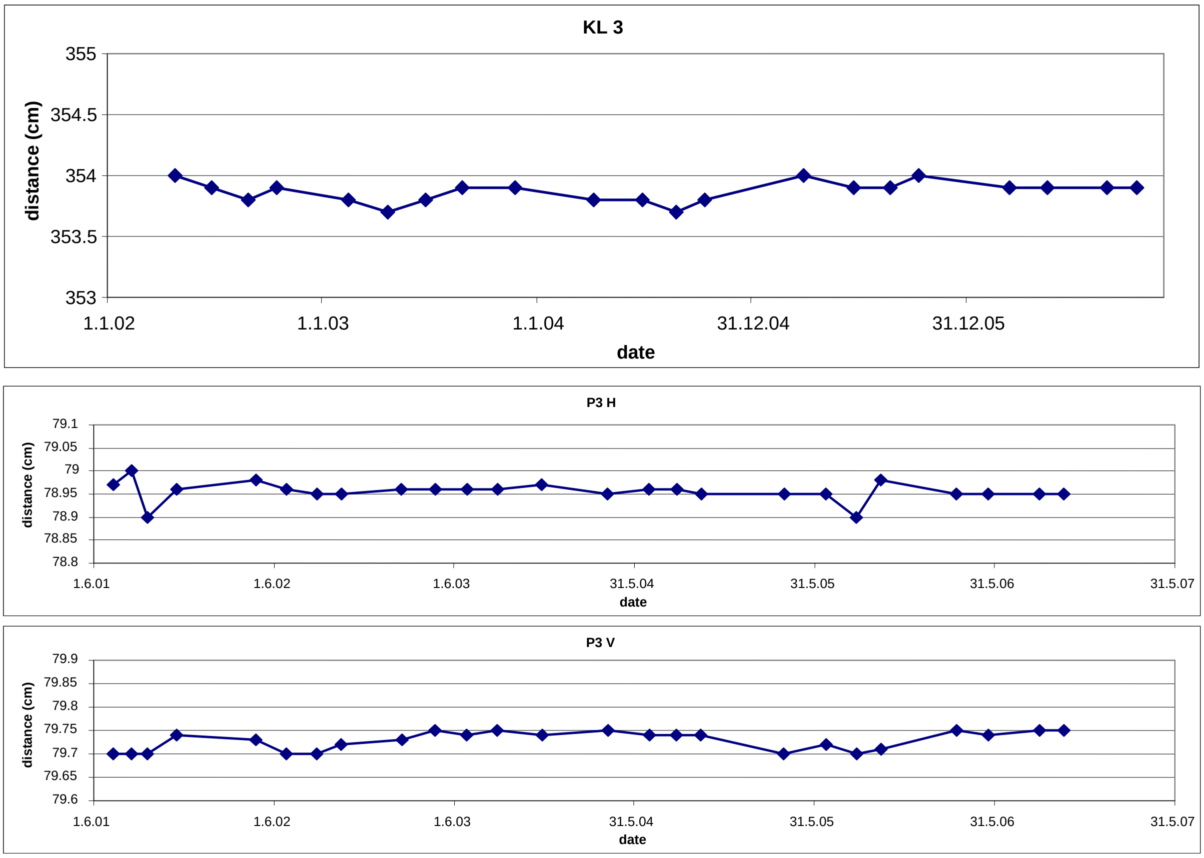

Fig. 3 Development of convergences of spatial (KL3) and linear (P3 horizontal and vertical) workings.

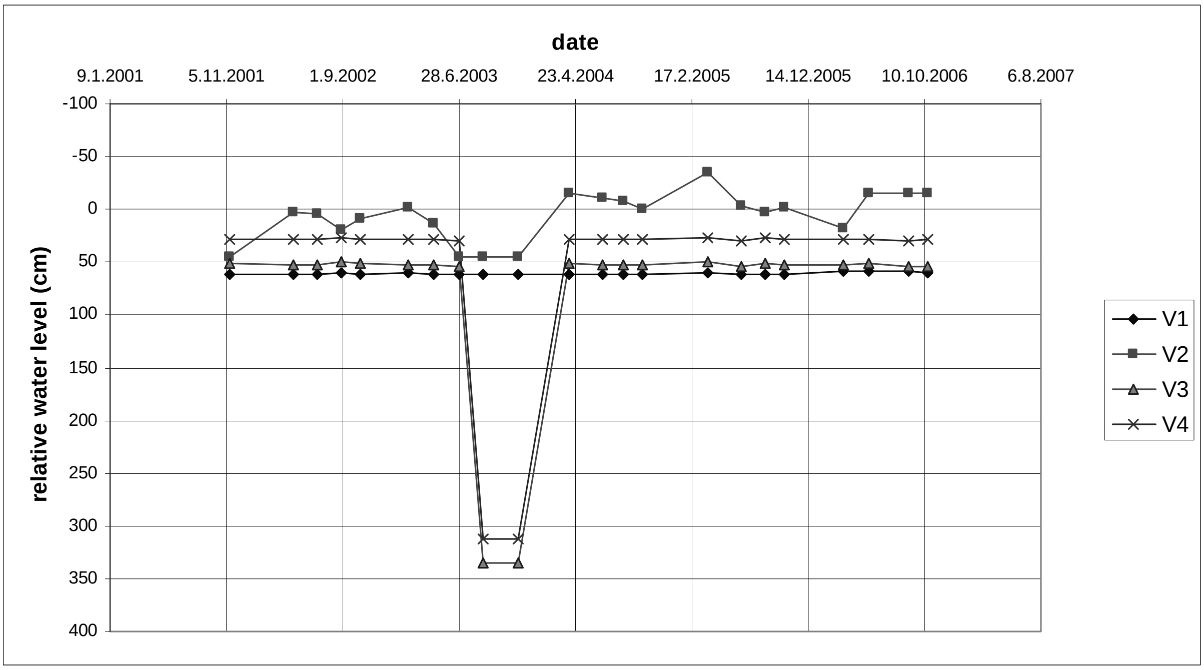

Fig. 5 Quarterly measurements of mine water fluctuation (locations V1 – V4).

or broken targets, have been noticed during the geological observations. These phenomena were documented in small "isolated" parts only, especially at the point named Stone Bridge. Therefore, we are able to confirm that we do not document significant movements of blocks on existing fissures. Distributed control and measurement system will include several sensors for continual measurement of rock blocks' movements. Sensors will be installed across the fissures that are in the most complicated conditions, e.g. superloaded pillar or suspended rock ceiling. Testing continual measurements are performed on locations KD1 and KD2 (see Figure 1).

GEOMECHANICAL MONITORING

Figure 3 presents examples of current results from measurements of cross-section convergences in linear and spatial workings. Vertical and horizontal directions (16 cross-sections) are always measured in linear profiles using convergence gauge with elastic (spring) system and optical reading. Laser range finder is used for evaluation of distances in large spatial workings (5 cross-sections). These measurements are practised quarterly. Obtained results reflect practically zero values of convergences in both types of workings (differences are detector errors only). One profile in vertical direction will be included into distributed system to test this type of measurement (testing measurement on KK1). These measurements resemble the measurements in caves – similar temperature, humidity … (e.g. Šebela et al., 2005).

HYDROGEOLOGICAL MONITORING

Mine waters in the Jeroným Mine can be divided into following types: running, influent and flowing waters, water accumulated in closed drainless expanses, waters in expanses with natural or man-made outflow). Mine water flow is significant, small drain exists in some parts during the whole year. The lowest parts at the bottom level of the mine are often flooded after intensive rains. Several water sources from the rock massif have also been detected, generally through old boreholes or caving spaces (Fig. 4). Today we documented changes of water level on selected locations. However, we are not able to measure flow rate; the only detected possibility for water to flow out is reconstructed in Jeroným ancestral adit.

In addition, observing of the mine water level fluctuation was started in 2001. Fixed meters were installed on four locations named V1 – V4; all measurements results are just relative values. The fluctuation of mine water level at the location V2 and one significant decrease of groundwater level at the locations V3 and V4 in 2003 is shown in Figure 5. This anomaly of water is not possible to analyzed in details because do not exist more information (two visual readout in mine space only). At the station V1, there is constant overflow up to now. These quarterly measurements prohibit evaluation of fluctuation velocity and sudden changes of water level.

Strain-gauge sensors were used for continual hydrogeological monitoring of water level fluctuation at the location V2 in March 2006 (station is now signed as KV2) and at the station V3 (KV3) in

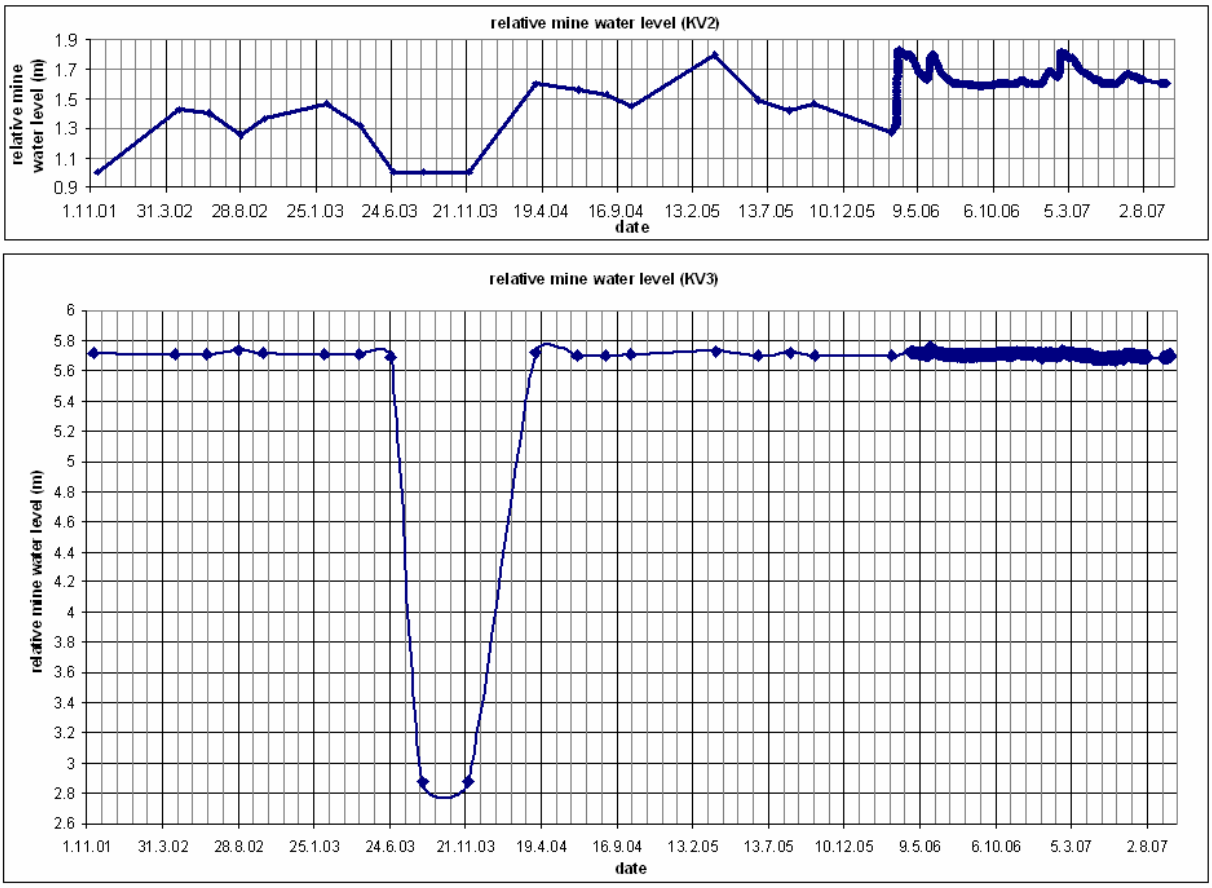

Fig. 6 Fluctuation of mine water levels on locations KV2 and KV3 (quarterly and continuous monitoring).

April 2006. The sampling time is one hour. Detailed description of instrumentation was presented by Knejzlík (2006 and contribution in this issue). Measured values are relative, again, and they were compared with the previous values (Fig. 6). Relative values are more suitable for quick orientation and mutual comparison than absolute altitudes.

Kaláb et al. (2007) presented detailed study of water in underground spaces and initial studies of hydrologic situation in the mine mentioned above. Comparison of mine water fluctuation with daily precipitation amounts was performed in time interval from March 2006 to October 2006. Temperature measurements were used as additional information for spring season, when quick snow-melt occurred (March 2006 – KV2). Data from Krásné - Údolí weather-station, which is located about 15 km far from the mine, were used. Following conclusions were determined:

- Sudden and significant increasing of mine water level is obviously related with marked changes of surface water amount (spates or snow-melt),
- Low increases of water level are not always dependent on precipitation amount and there probably exists also another influencing factor: ground water level in adjacent rock massive (the fluctuation of the groundwater level is influenced by precipitation, air pressure changes and earth tides, see Stejskal et al., 2005), presence of ponds above the Jeroným Mine, …,
- Gradual and long-term fluctuation of mine water level exhibits any significant relation with daily precipitation amounts on surface.

Preparation of more detailed conclusion will be possible after a longer period of observation.

SEISMOLOGICAL MONITORING

The first idea to build a seismological monitoring occurred together with the planning of the reconstruction of the Jeroným adit in 2004. Continuous seismological monitoring was necessary because blasting operations were performed as a part of reconstruction procedure. Three seismometers SM3 in geographical orientation are anchored on a concrete pillar near spatial working K4 (see Figure 1). Seismic recording apparatus PCM3-EPC3 (Knejzlík and Kaláb, 2002) with special modification for environment with high air humidity and drip water has been installed directly in the mine working. Using telemetry (GSM modem) seismological records are

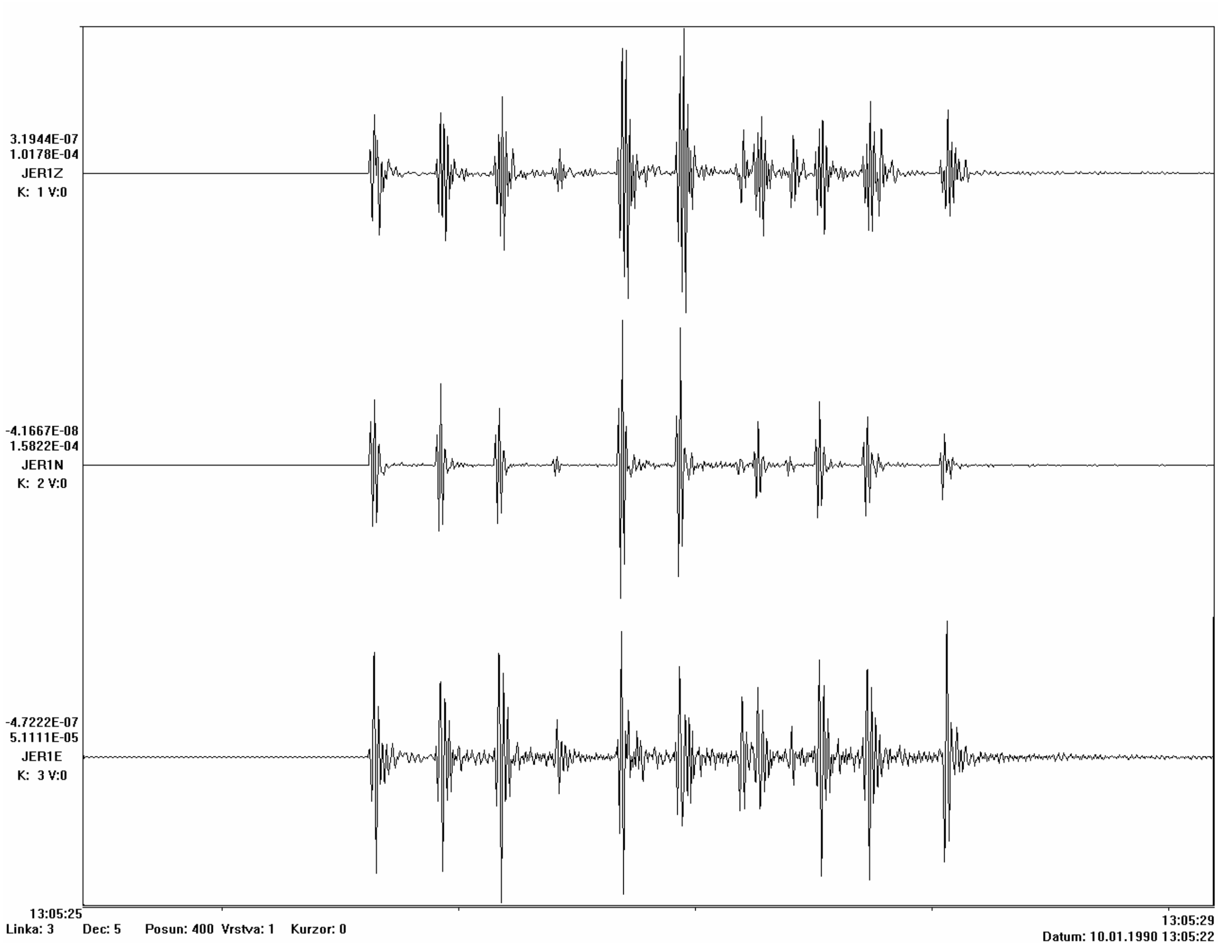

Fig. 7 Example of wave pattern of a blast generated in the Jeroným adit (horizontal axis is local time, top down axis are vertical, N-S and E-W components).

transferred to the Institute of Geonics. It is also possible to control the data acquisition system. At the beginning of the year 2006, the adit reconstruction was completed and seismic load of mine working decreased.

Seismic station was named JER1. Seismic recording is based on trigger regime, sampling frequency of digital signal is 250 Hz per channel, low significant bit has a value of $7.6\text{x}10^{-9}$ m.s^{-1} after adaptation of seismological system.

Records obtained on this seismic station can be divided into following types:

- Technical seismicity:
  - blasting operations – during reconstruction of theadit, in adjacent quarries (Krásno, …)
  - traffic – on road above the Jeroným Mine
- Natural seismicity:
  - parts of distant intensive earthquakes
  - microearthquakes from West Bohemia

BLASTING OPERATIONS IN THE JERONÝM ADIT

Wave patterns of blasting operation during reconstruction of the Jeroným adit have typical shapes. They consist of several wave groups that represent individual stages of blasting (Fig. 7). More than 250 events were recorded simultaneously.

Results from blasting operation during reconstruction of the Jeroným adit (2005 and 2006) are presented at Figure 8. Main aim of the monitoring was to avoid damages to the monuments in the mine. Using the Czech technical standard 73 0040 and an expert opinion, the limit value of maximum oscillation velocity in the working was fixed to 0.1 mm.s^{-1}. It was necessary to regulate parameters of blasting operations when this value was exceeded (see it in Figure 8 – May 2005, October 2005, December 2005 and January 2006). Maximum measured velocity value, 0.16 mm.s^{-1}, was detected at the Z component (Kaláb and Lednická, 2006).

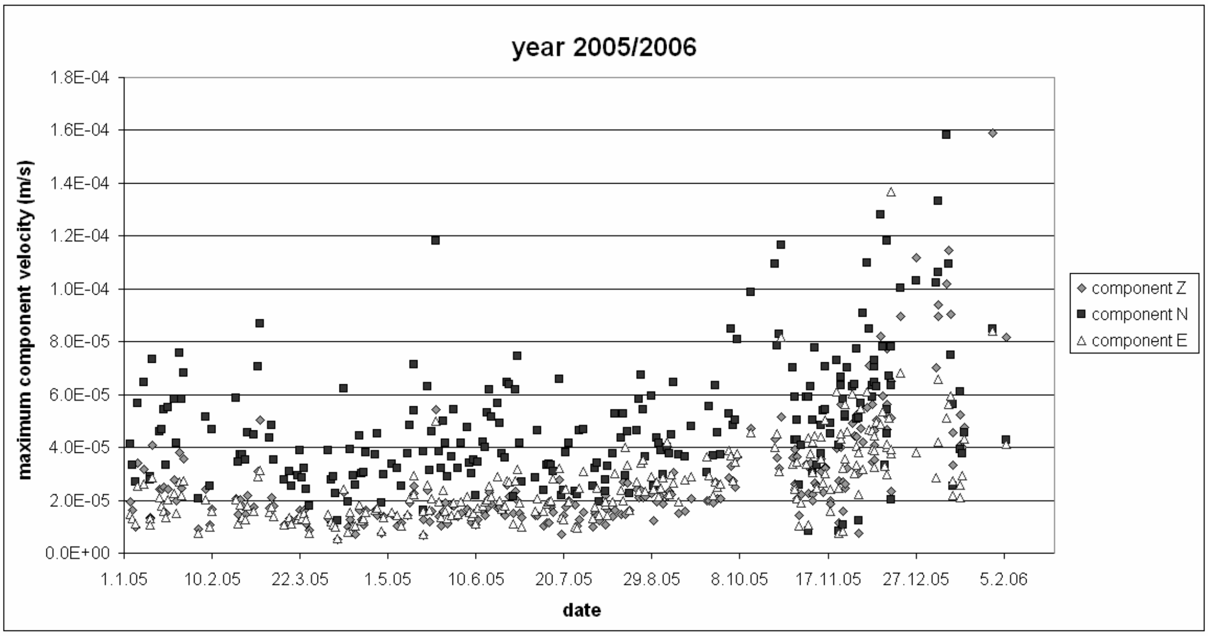

Fig. 8 Maximum values of component velocity generated by blasting operations in Jeroným adit in the years 2005 and 2006 *(date in format day.month.year).*

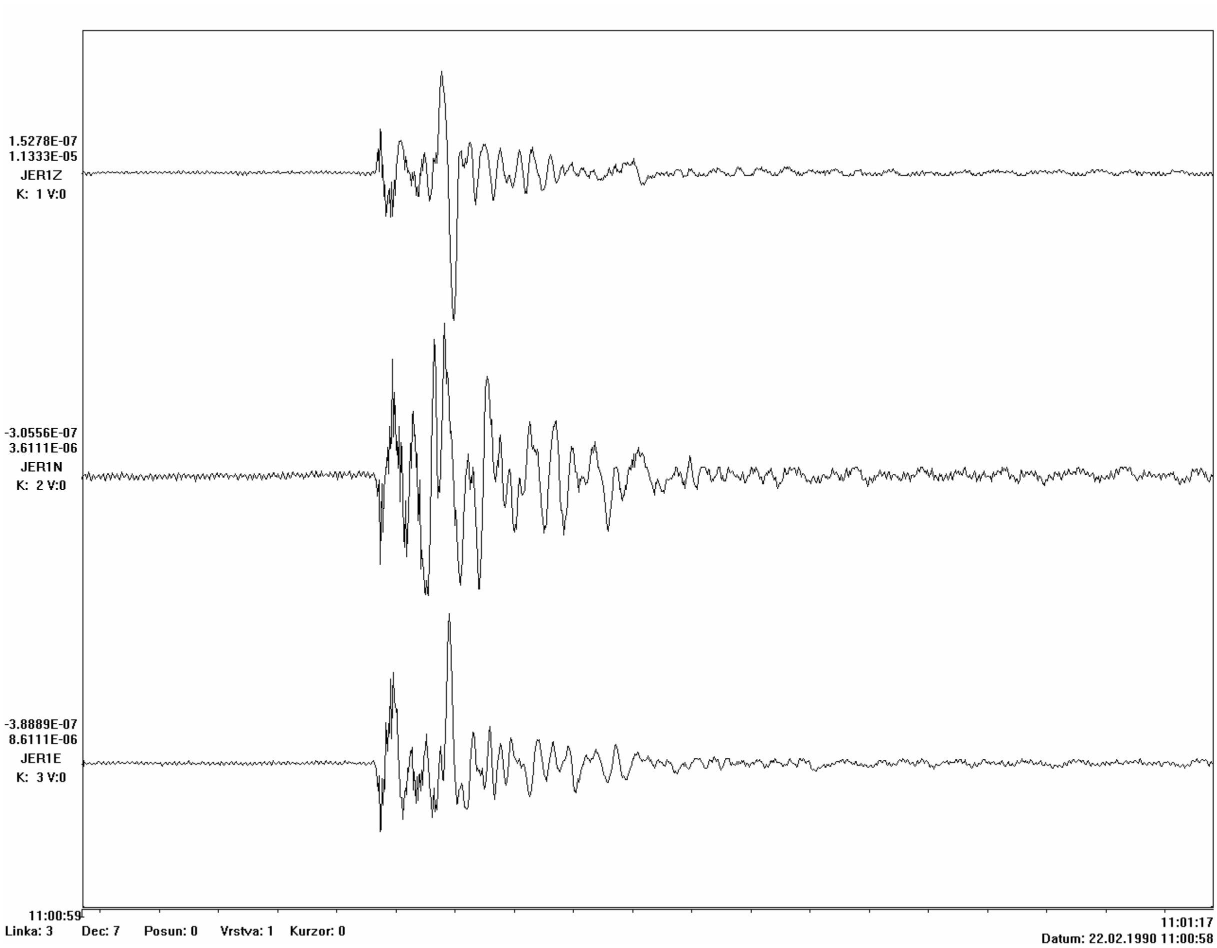

Fig. 9 Example of wave pattern of blast generated in the quarry Krásno (recorded by station JER1).

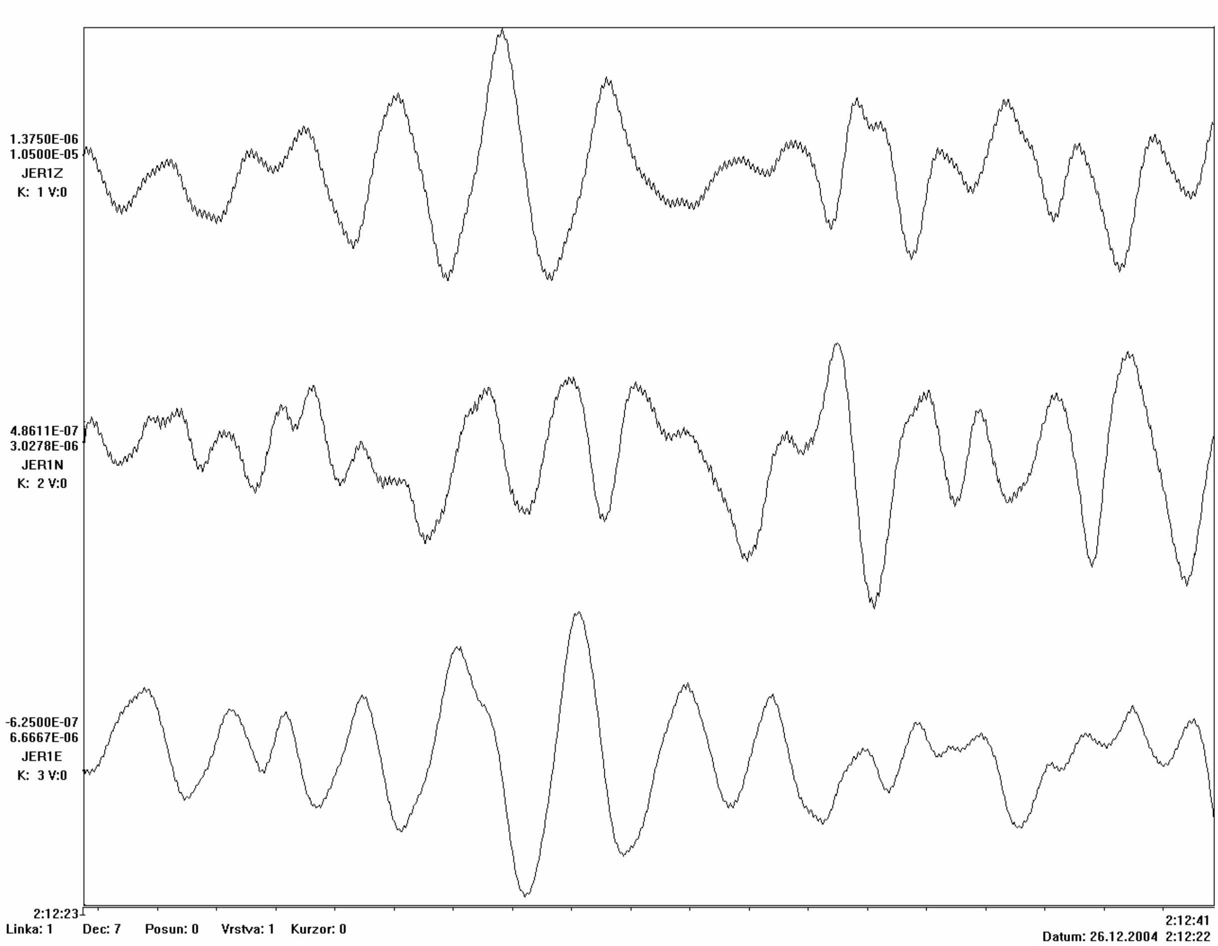

Fig. 10 Example of distant earthquake record – non-identified part of earthquake from Indonesia.

BLASTING OPERATIONS IN ADJACENT QUARRIES

Vibrations generated by blasting operations in quarries do not represent much significant seismic load on the mine. Usually, maximum values from the nearest quarry (feldspathic quarry Krásno) are within the range of 10^{-3} – 10^{-2} mm.s^{-1} (not too significant for stability assessment). Example of wave pattern is in Figure 9.

TRAFFIC

There is a road from Prameny to Sokolov situated on the surface above the Jeroným Mine. Heavy trucks on the road above the mine generated problems with high seismic load in the mine working. However, prohibition of heavy trucks on this road resulted in seismic load decrease.

Maximum values of oscillation velocity generated by traffic are now up to 10^{-2} mm.s^{-1}.

INTENSIVE DISTANT EARTHQUAKES

Trigger parameters and frequency range of the station JER1 seismic channel enables to record only small parts of intensive distant earthquakes – heavily identified wave group. In addition, maximum recording time for one record is set to 60 seconds as this is sufficient for local events. Example of wave pattern is in Figure 10, maximum values of velocity are usually up to 10^{-2} mm.s^{-1}.

MICROEARTHQUAKES FROM NORTH-WEST BOHEMIA/VOGTLAND REGION

The North-West Bohemia/Vogtland is the nearest region with natural seismicity (Team, 2000) that is located about 25 km to the west from the mine. Weak earthquakes and swarm are detected practically all the time by seismic networks operated by Prague and Brno institutes. Seismic stations near Lazy village (about 12 km from the mine) and Částkov village (about 20 km) are the nearest permanent stations from investigated region. Seismic load of the Jeroným Mine by seismicity from west Bohemia swarm region is discussed in Kaláb (2003).

Since 9th until 10th February 2007, almost 1500 microearthquakes with the magnitude range from 0.5

Table 1 Summary of data from swarm occurred in West Bohemia (9th till 10th February 2007).

Seismic staiton in Jeroným Mine					Data from Bulletins of seismic events recorded by the Czech Regional Seismological Network
date	time	Z	N	E	
9.2.2007	14:37:23	1.53E-06	2.74E-06	1.53E-06	FEB09 133721.1 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.52E h=1km WEST BOHEMIA SWARM (GFU)
					NKC ePg 133722.1, eSg 133723.4 (TV=0.2 AV=23.7 MV=0.9), Dc=0.06
9.2.2007	14:53:16	3.83E-06	7.17E-06	3.13E-06	FEB09 135312.6 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.50E h=2km WEST BOHEMIA SWARM (GFU)
					NKC ePg 135313.5, eSg 135314.8 (TV=0.2 AV=163.3 MV=1.7), Dc=0.05
9.2.2007	15:35:12	3.03E-06	4.83E-06	2.83E-06	FEB09 143508.3 CZECH AND SLOVAK REPUBLICS(547) 50.21N 12.49E h=5km WEST BOHEMIA SWARM (GFU)
					NKC ePg 143509.7, eSg 143510.9 (TV=0.2 AV=83.5 MV=1.4), Dc=0.03
9.2.2007	17:12:47	2.31E-06	2.92E-06	2.10E-06	FEB09 161243.6 CZECH AND SLOVAK REPUBLICS(547) 50.22N 12.43E h=10km WEST BOHEMIA SWARM (GFU)
					NKC ePg 161245.4, eSg 161246.5 (TV=0.2 AV=106.4 MV=1.5), Dc=0.02
9.2.2007	17:14:40	6.33E-06	1.31E-05	6.44E-06	FEB09 161437.9 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.51E h=2km WEST BOHEMIA SWARM (GFU)
					NKC ePg 161438.9, eSg 161440.3 (TV=0.2 AV=176.7 MV=1.7), Dc=0.05
9.2.2007	17:32:20	2.58E-06	2.82E-06	3.35E-06	FEB09 163216.8 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.45E h=6km WEST BOHEMIA SWARM (GFU)
					NKC ePg 163218.5, eSg 163219.6 (TV=0.2 AV=92.2 MV=1.5), Dc=0.03
9.2.2007	17:40:10	2.36E-06	3.42E-06	2.04E-06	FEB09 164006.3 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.46E h=6km WEST BOHEMIA SWARM (GFU)
					NKC ePg 164007.8, eSg 164009.1 (TV=0.2 AV=81.8 MV=1.4), Dc=0.03
10.2.2007	0:15:41	3.21E-06	4.42E-06	2.54E-06	FEB09 231535.6 CZECH AND SLOVAK REPUBLICS(547) 50.19N 12.44E h=9km WEST BOHEMIA SWARM (GFU)
					NKC ePg 231537.9, eSg 231539.0 (TV=0.2 AV=79.5 MV=1.4), Dc=0.04
10.2.2007	3:14:56	2.96E-06	3.81E-06	2.68E-06	FEB10 021452.2 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.44E h=8km WEST BOHEMIA SWARM (GFU)
					NKC ePg 021454.1, eSg 021455.3 (TV=0.2 AV=85.3 MV=1.4), Dc=0.03
10.2.2007	4:58:13	3.86E-06	5.92E-06	4.61E-06	FEB10 035810.1 CZECH AND SLOVAK REPUBLICS(547) 50.19N 12.44E h=8km WEST BOHEMIA SWARM (GFU)
					NKC ePg 035812.3, eSg 035813.5 (TV=0.2 AV=100.0 MV=1.5), Dc=0.04
10.2.2007	5:00:18	3.75E-06	4.67E-06	3.53E-06	FEB10 040014.0 CZECH AND SLOVAK REPUBLICS(547) 50.19N 12.44E h=8km WEST BOHEMIA SWARM (GFU)
					NKC ePg 040016.0, eSg 040017.1 (TV=0.2 AV=107.5 MV=1.5), Dc=0.04
10.2.2007	5:59:42	5.89E-06	3.11E-06	3.83E-06	FEB10 045938.5 CZECH AND SLOVAK REPUBLICS(547) 50.20N 12.48E h=7km WEST BOHEMIA SWARM (GFU)
					NKC ePg 045940.7, eSg 045941.5 (TV=0.2 AV=189.0 MV=1.8), Dc=0.04
10.2.2007	6:13:14	3.18E-06	3.11E-06	2.79E-06	FEB10 051310.1 CZECH AND SLOVAK REPUBLICS(547) 50.21N 12.45E h=6km WEST BOHEMIA SWARM (GFU)
					NKC ePg 051311.3, eSg 051312.8 (TV=0.2 AV=55.4 MV=1.2), Dc=0.02
10.2.2007	7:29:12	3.51E-06	3.92E-06	3.51E-06	FEB10 062907.2 CZECH AND SLOVAK REPUBLICS(547) 50.19N 12.46E h=7km WEST BOHEMIA SWARM (GFU)
					NKC ePg 062909.1, eSg 062910.3 (TV=0.2 AV=135.5 MV=1.6), Dc=0.04

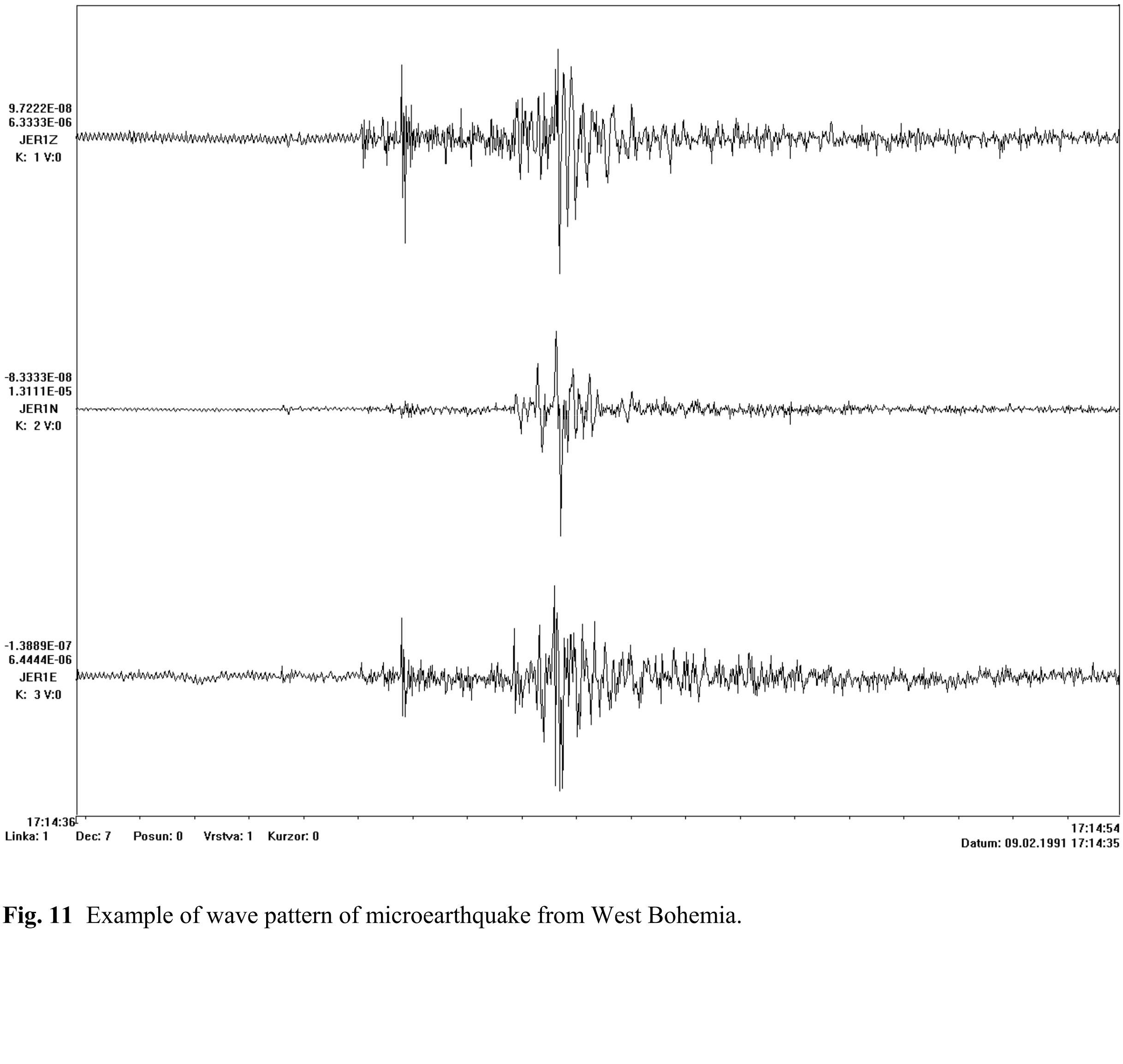

Fig. 11 Example of wave pattern of microearthquake from West Bohemia.

to 1.8 occurred at the southern edge of the Nový Kostel area (see *http://www.ig.cas.cz/cz/seismicka-sluzba/seismicke-bulletiny/index.php*). Several more intensive events (magnitude range MV 0.9 – 1.8; according to Nový Kostel seismic station) was recorded at the seismic station in Jeroným Mine. Summary of these microearthquakes recorded by JER1 station is presented in Table 1. Local time and recorded maximum component amplitudes [$mm.s^{-1}$] are displayed in the left part of the table, data from Bulletin of seismic events recorded by the Czech Regional Seismological Network are in the right part. Maximum velocity recorded in mine is $1.31*10^{-5}$ $mm.s^{-1}$. Example of wave pattern is in Figure 11.

CONCLUSION

The Jeroným mine is a monument with European significance. At present, it is necessary to ensure suitable stability conditions of this medieval mine working and to minimize degradation of the old and weak rock massive in order to protect the workers, and later public visitors. Main aim of this contribution was to summarize current results from geomechanical and seismological measurements.

The presented results from the measurements show the mine working as a stable complex, which is a very important finding. Thanks to this fact it is possible to continue in preparation of this monument for opening it to public. The Jeroným mine is now used as an experimental laboratory for evaluation of new instrumentation (see Knejzlík and Rambouzský, 2008) and methods to detect rock deformation and seismic load. The most interesting pieces of information are the evaluation of mine water fluctuation in the V2 location and seismological monitoring.

The measurements described above are very important, especially if the reconstruction in the mine is going to continue. In such case, a gallery connecting the Old Mine Workings and Abandoned Mine Workings parts is planned first.

ACKNOWLEDGEMENT

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REFERENCES

Bernard, J.H. et al.: 1981, Mineralogy of the Czechoslovakia. Academia Prague, 2nd printing, (in Czech).

Kaláb, Z.: 2003, Evaluation of seismic load of the medieval mine Jeroným, Czech Republic. Acta Montanistica Slovaca. Vol. 8(2003), No.1, Košice, Slovakia, 36–41, (in Czech).

Kaláb, Z. and Lednická, M.: 2006, Interpretation of seismic records of blasting operations performed in gallery Jeronym in Cista. Transactions, Civil Engineering Series, Vol. VI, No. 2/2006, 155–160, (in Czech).

Kaláb, Z., Lednická, M and Kukutsch, R.: 2007, Water in underground spaces in Čistá, mine Jeroným. Journal Coal, Mineral and Geological Survey, Czech Republic, No.5/2007, 31–35, (in Czech).

Kaláb, Z., Knejzlík, J., Kořínek, R. and Žůrek, P.: 2006, Cultural monument Jeroným mine, Czech Republic – Contribution to the Geomechanical Stability Assessment. Publs. Inst. Geophys. Pol. Acad. Sc., M-29(395), Warszawa, 137–146.

Knejzlík, J.: 2006, Distributed system for monitoring in the Jeroným mine. Transactions, Vol. VI, No. 2/2006, 181–187, (in Czech).

Knejzlík, J. and Rambouský Z.: 2008, Current solution for distributed control and measurement system in the Jeroným mine – Modular system. Acta Geodyn. Geomater., Vol. 5, No. 2(150), 205–212, (in this issue).

Knejzlík, J. and Kaláb, Z.: 2002, Seismic Recording Apparatus PCM3-EPC. Publs. Inst. Geophys. Pol. Acad. Sc., M-24(340), 187–194.

Stejskal, V., Skalský, L. and Brož, M.: 2005, Analysis of Factors Forming the Groundwater regime in the West Bohemian Seismoactive Region. Acta Geodyn. Geomater., Vol. 2, No. 4(140), Prague, 23–37.

Šebela, S., Gosar, A., Košťák, B and Stemberk, J.: 2005, Active Tectonic Structures in the W Part of Slovenia – Setting of Micro-Deformation monitoring Net. Acta Geodyn. Geomater., Vol. 2, No. 1(137), Prague, 45–57.

Team: 2000, Monographic issues. Studia geophysica et geodaetica, Vol. 44/2 a 44/4, AS CR, Prague.

Žůrek, P. and Kořínek, R.: 2001/2002, Opening of the Medieval Jeroným Mine in the Czech Republic to the Public. Journal of Mining and Geological Science, Belgrade, Vol. 40-41, 51-72.

Žůrek, P. and Kořínek, R.: 2004, Opening of the Medieval Jeroným Mine in the Czech Republic to the Public. Acta Montanistica Slovaca, 8., 96–100.

Žůrek, P., Kořínek, R., Michalčík, P., Štěpánková, H., Daněk, T., Kukutsch, R., Kaláb, Z., Knejzlík, J. and Lednická, M.: 2005, Global analyses of geotechnical problems in the Jeronym mine, Period 2004-2005. Journal Coal, Mineral and Geological Survey, Czech Republic, No.9/2005, 31–34, (in Czech).

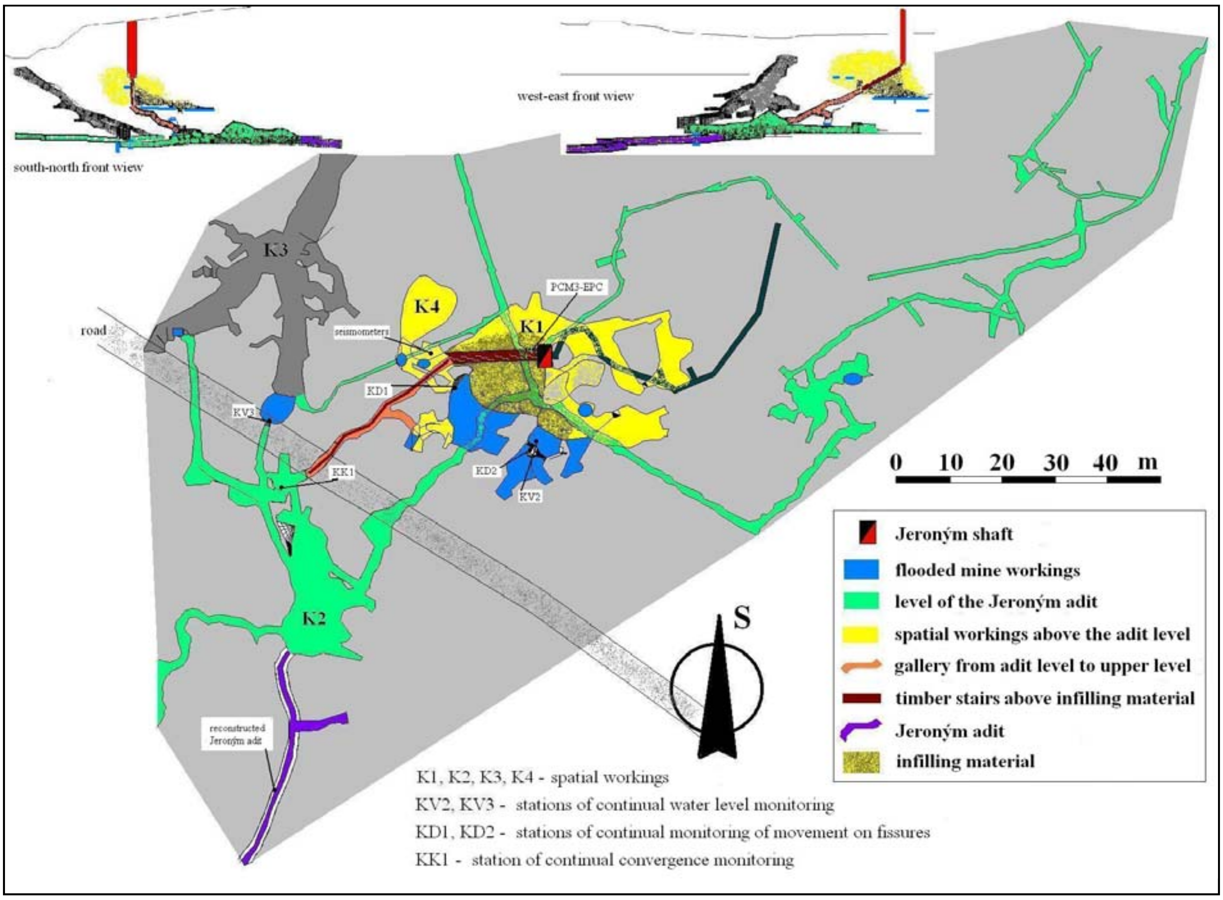

Fig. 1 Sketch of Jeroným Mine (Abandoned Mine Workings) including cross-sections – see text.

Fig. 4 Example of water discharges through caving space.