Mine Water Movement in Shallow Medieval Mine Jeroným (Czech Republic)

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Abstract

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. In addition, observing of the mine water level fluctuation was started in 2001 (quarterly). Strain-gauge sensors were used for continual hydrogeological monitoring of water level fluctuation at the location V2 and V3 in 2006. The sampling period is one hour.

Key words: medieval Mine Jeroným, mine water, hydrogeological monitoring, Czech Republic

Introduction

Geological pattern of Slavkovský les Mountain (West Bohemia) is ground for a lot of metalliferous deposit origination. Deposits of precious metals were prospected above all. Silver, gold, cuprous and zinc ores were found in the area under discussion. However, tin were exploited mostly. Chemical analysis confirmed that tin from this area was used in artifact from year 2000 B.C. At first, our ancestors had collected raw materials from earth surface or watercourses; gradually they began searching for them in the depths. The beginnings of underground mining in the locality date back to the first half of the 16th century. The mining and sporadic exploitation then continued with many interruptions till the beginning of the 20th century. According the historic data, the depth range of mine workings is approximately 50 m (according Tomíček, 2007, Žůrek and Kořínek, 2001/2). Medieval Jeroným Mine near Čistá (Sokolov district) is a monument with European significance because it presents the unique and significant example of mining works since the 16th century.

The first steps leading to the preservation of the set of mine workings, Jeroným, and the opening of the complex to the public have already been taken. For the uniqueness, the extent of the mine workings and a high degree of preservation of lately medieval mine workings, the Ministry of Culture declared the Jeroným Mine to be a cultural monument on February 1990. The geomechanical stability assessment of the cultural monument, Jeroným Mine, deals with the issues of the evaluation of the geomechanical condition of the rock mass and the mine workings

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 by 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. Today, both parts have their own entrances. The geology and mining history of this deposit was published in details, e.g. by Bernard and Suček, 2000, Žůrek and Kořínek (2001/2).

The assessment of the stability of historical structures is always a difficult matter because there is a lack of information available for this assessment. In the case of the Jeroným Mine any structure, layout and extent of mine spaces and any exact time of their origin are not known (during a fire of the archives at Horní Slavkov, all mine documentation was destroyed). At the beginning of detailed analyses, any local geological structure, hydrogeological situation (pathways of mine water and surface water) and petrophysical properties of rocks (with various degrees of weathering) are not known. The complicated structure of stopped-out spaces supplemented with pillars, blocks of rocks in the hanging wall, and others do not make it possible to assess without measurement the stress conditions and the stability of particular elements of the mass. The hydrogeological situation is a very significant factor that can change suddenly and thus can cause unexpected hazardous conditions. This article is focused primarily on hydrogeological monitoring in Abandoned Mine Workings.

Geomechanical and seismological monitoring

The purpose of present geomechanical and seismological monitoring in the Jeroným Mine is evaluation of the geomechanical stability of the part of the Abandoned Mine Workings (e.g. Kaláb et al., 2006, Žůrek 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 deep under the surface. Regular measurements for the geomechanical stability assessment of Jeroným Mine have been carried out since 2001 – primarily only periodical (quarterly) measurements and since the year 2004 – some continual measurements.

Summary of quarterly monitoring:

- Geological monitoring (observation of crack development in the mine workings, about 10 measuring points - plaster and glass targets) - up to now these observations do not document significant changes in these measuring points
- Geomechanical monitoring (development of changes in convergence cross-sections of linear and spatial workings, 21 measuring points in linear and spatial workings) – these measurements also do not document significant changes in measuring points
- Hydrogeological monitoring (observation of mine water level fluctuation at four places) - significant changes in mine water level fluctuation especially at point called Stone Bridge
- Seismological monitoring - started with the reconstruction of old drainage adit (2004), seismic apparatus PCM3-EPC with seismometers anchored on concrete pillar in mine working (blasting operations – adit reconstruction, adjacent quarries, traffic – road above the mine, earthquakes – intensive distant, microearthquakes from West Bohemia)

Continual monitoring using distributed control and measurement system includes:

- Measurement of the mine water level fluctuation (two points)
- Continual measurement of rock blocks' movements (four sensors are installed across the fissures)
- Measurements of cross-section convergences in linear (one test point) and spatial workings (one point will be realized in June 2008 using laser distance meter)
- Measurement of temperature in mine workings (two points)
- Measurement of rock massif stress changes using compact conical ended borehole monitoring probe – Knejzlík et al., 2008 (two points)

Distributed control and measurement system is integrated to the existing seismic recording station equipped by data transmission via GSM network to interpretation centre (Knejzlík, Kaláb, 2002, Knejzlík, 2006).

Hydrogeological situation in mine spaces

Two locations for measurement of the mine water level fluctuation are situated above gallery level near the Jeroným shaft (V1 and V2), rest of the two ones are approximately at level of the Jeroným adit (V3 and V4). Strain-gauge sensors are used for continual hydrogeological monitoring of water level fluctuation at the location V2 since March 2006 and at the station V3 since April 2006. The sampling time is one hour. Knejzlík (2006) presented detailed description of instrumentation. Measured values are relative, again, and were compared with the previous values. Relative values are more suitable for quick orientation and mutual comparison than absolute altitudes. The most important results were obtained from part called Stone Bridge (V2); results from this measurement (Fig. 1, Fig. 2) are briefly described in this chapter.

Figure 1 *Fluctuation of mine water level on locations V2 (quarterly measurements are presented by bigger squares; continuous measurements are presented by small rhombs)*

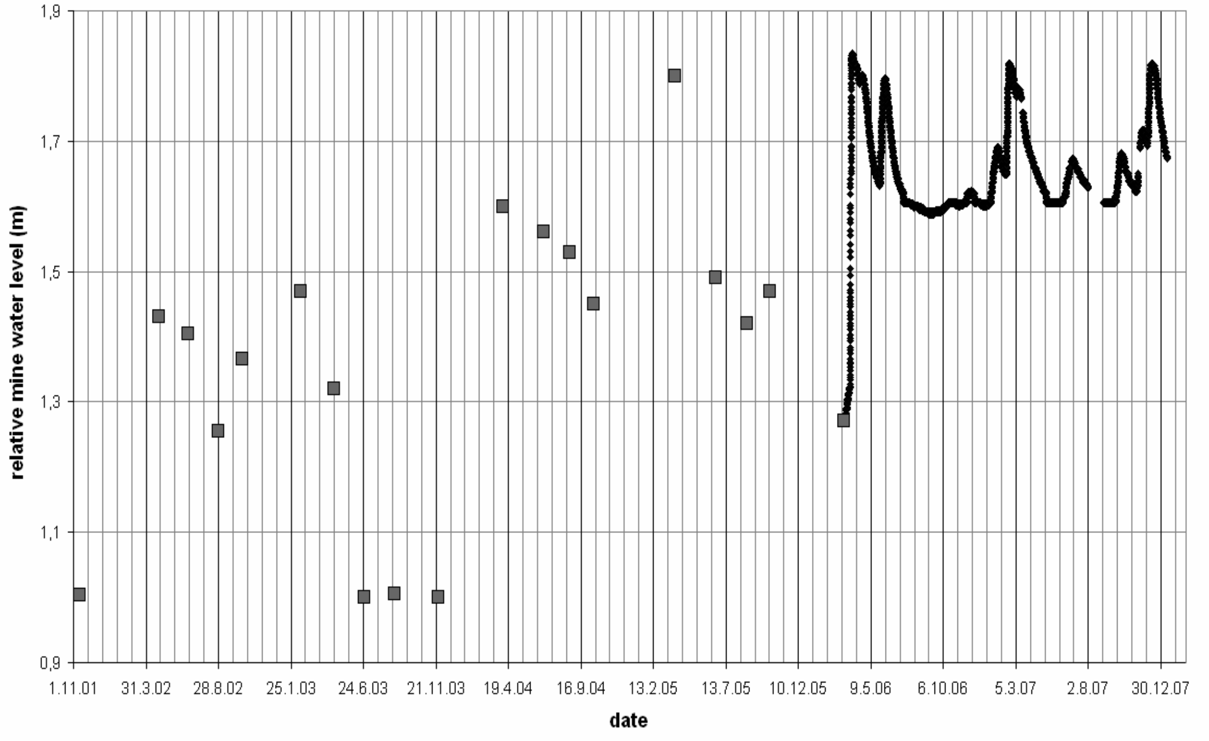
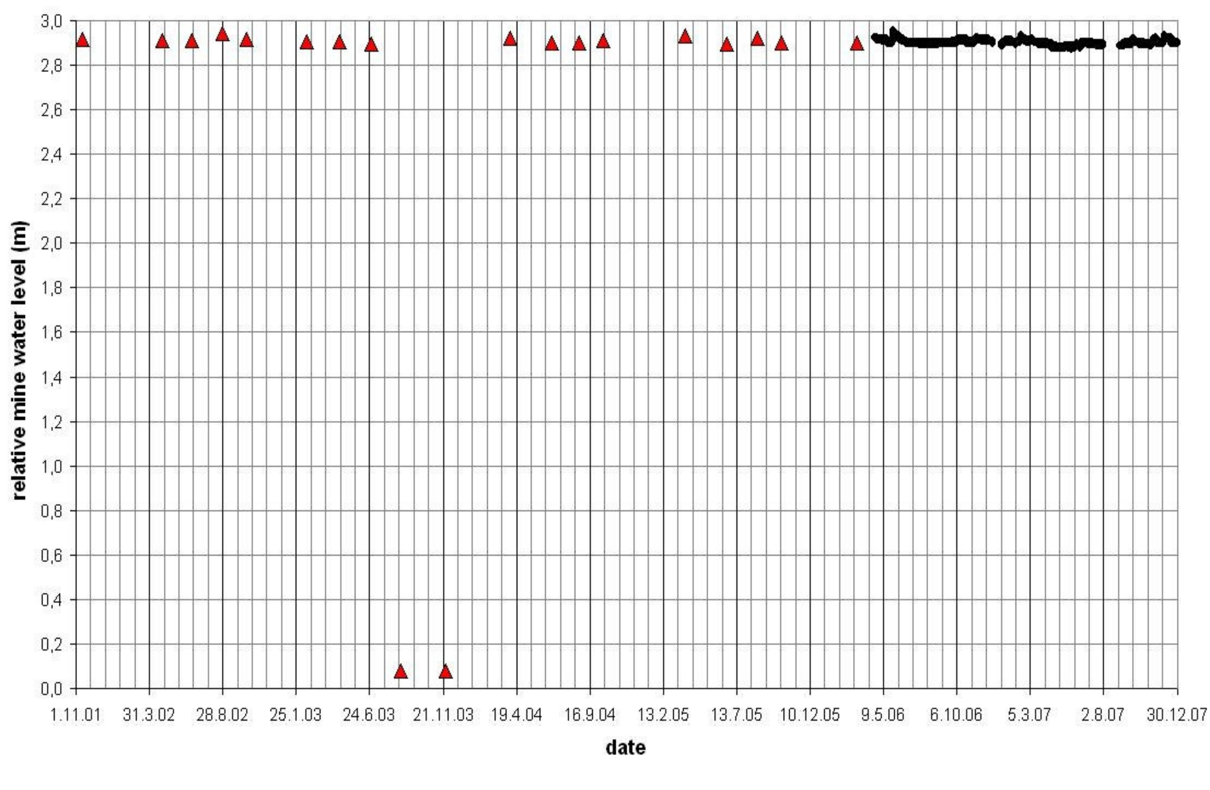


Figure 2 *Fluctuation of mine water level on locations V3 (quarterly measurements are presented by bigger squares; continuous measurements are presented by small rhombs)*



Fluctuations of groundwater level do not offer detailed logical explanation. It is evident that water gets to the mine solely by seeping surface water as gravity water. The drainage of the mine is done via the reconstructed drainage adit. A part of mine workings below the adit level of the Jeroným Mine as well as some mine workings above the adit level (drainless spaces) are permanently flooded with closed mine water. In addition to visible drainless spaces, other spaces may exist in the mass that could be closed by the caved areas already existing and that prevented any communication with mine water. As is mentioned above, significant fluctuation is detected on the V2 location (Fig. 2) that is situated at bottom of bulk material in mine room named K1. The measured changes range up to 1 m (small values in graph represent decrease of groundwater level). The evaluation of these factors according to the significance of adverse effects is difficult. In all cases, they are such factors the manifestations of which are, from the temporal point of view, long-term. In the authors' opinion, the most serious factor is water flow pressure and related suffusion.

Measurement on the V3 location (Fig. 3), excluding measurement at autumn 2003, doesn't show changes – permanent overflow from this separated space is documented. Significant decrease of mine water occurred in 2003. The measured relative value was about 3 m. The evaluation of this fact is difficult because it is not know volume of flooded space and bottom pattern (bottom is covered by stones). Also, dynamics of this decreasing is not possible to evaluate from quarterly observations. One of the hypothesis is existence of next drainage adit that is permanently defunctioning.

Kaláb et al. (2007) presented detailed study of water in underground spaces and initial studies of hydrologic situation in the mine. 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 – V2). 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
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Preparation of more detailed conclusion will be possible after a longer period of observation.

Conclusion

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 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, decrease of mine water in the V3 in 2003 and seismological monitoring. From the hydrogeological point of view, chemical analysis of mine water and coloring experiment to detect interconnection of separated part provided interesting results.

Simple plane finite element model (Plaxis programming system), with limited possibilities of respecting real discontinuous environment, enables to obtain basic idea about the stress-strain and stability situation in the area of interest and also enables the realisation of parametrical computations. Values of maximum total displacements, localized above the roof of chambers, show the values in the range of 0.3-1.7 mm, in relation to the analyzed sections. Stresses are concentrated primarily to the lateral parts of the section, particularly in the transitional zones between the bottom of the chamber and the sidewalls and in the area of other sharp projections (Hrubešová et al., 2007). Results of the first phase of mathematical modelling as well as the results of the geotechnical monitoring document sufficient stability of the present situation of the analyzed chamber (K2) of mine Jeroným.

Supplement

Supplements 1- 3 document types of mine water in Mine Jeroným, supplements 4- 6 document measured locations V2 and V3 (including of decrease of mine water in 2003) and supplement 7 – 8 document mining activities from the 16-17th centuries.

Acknowledgements

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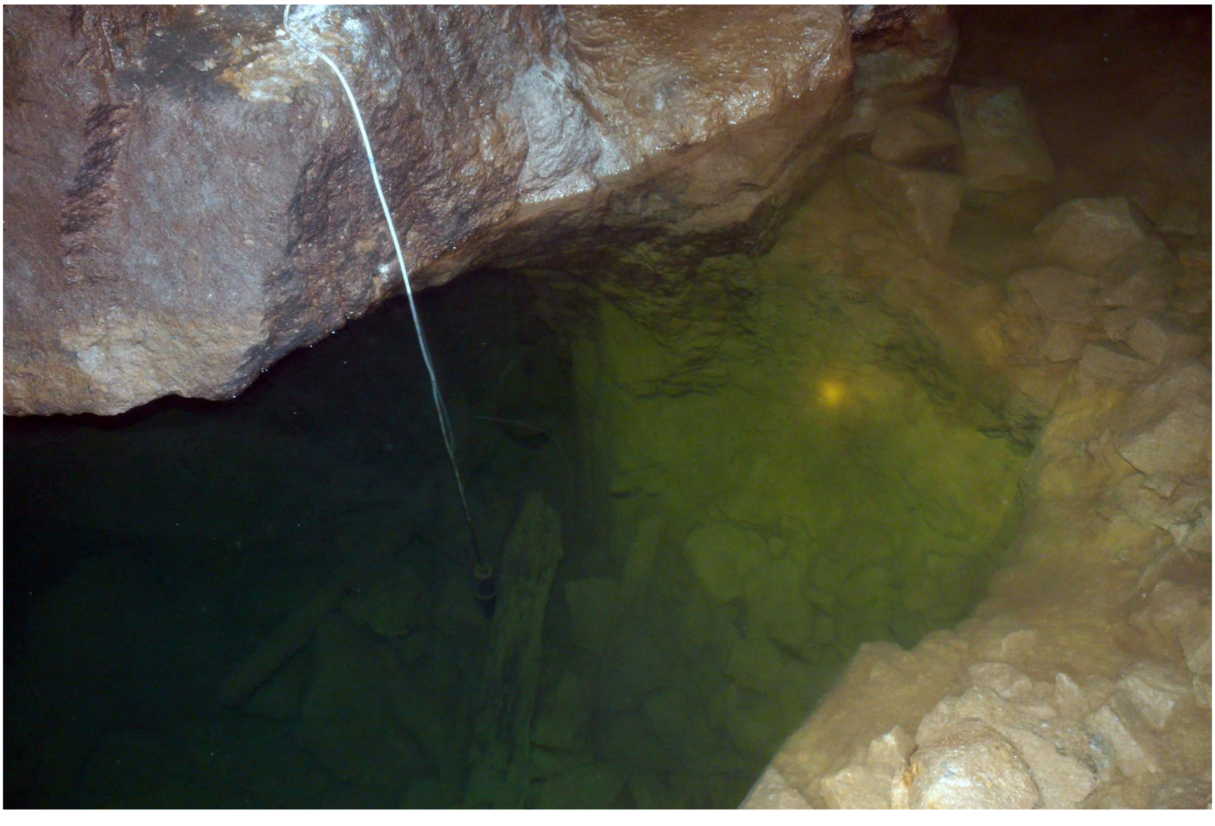
Supplement 1 *Backwater*

Supplement 2 *Running water from crack*

Supplement 3 *Outgoing water from backwater (V3 location)*

Supplement 4 *Probe for continual measurement of fluctuation of mine water level on location V2*



Supplement 5 *Probe for continual measurement of fluctuation of mine water level on location V3*

Supplement 6 *Sudden loss of water on V3 location in 2003 (fixed meter for quarterly measurements)*

Supplement 7 *An example of manually stoped-out adit from the 16-17th centuries*

Supplement 8 *An example of firing work (soot in underground spaces)*