# HYDROGEOLOGIC AND HYDRAULIC CONDITIONS OF OLD MINE WORKINGS OF THE FORMER JERONÝM MINE

# HYDROGEOLOGICKÉ A HYDRAULICKÉ POMĚRY STARÝCH DŮLNÍCH DĚL BÝVALÉHO DOLU JERONÝM

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**Abstract**

The Jeroným Mine, situated in the locality of the Slavkovský les Protected Landscape Area, is a unique heritage site associated with mining in the 15$^{th}$ and 16$^{th}$ centuries. To make this mine working accessible to the public, it is necessary in the first place to stabilize underground voids and to ensure such internal microclimatic conditions so that any degradation of the mine working and any hazard to workers performing restoration operations and later to visitors will not occur. The contribution deals with the factors conditioning and affecting the stability of this system of mine workings.

**Abstrakt**

Hydrogeologické poměry hornicky hlubinně otevřeného ložiska nerostné suroviny a následné antropogenní změny přirozených hydraulických poměrů lokality jsou významným činitelem, ovlivňujícím jak hydrogeologické a hydrologické poměry oblasti, tak i geomechanické projevy horninového masivu. Jsou nedílnou součástí komplexního a systémového posouzení hornicky postižené oblasti i dlouhodobě po ukončení těžebních prací.

**Key words:** Jeroným Mine, old mine workings, hydrogeology.

## 1 INTRODUCTION

In case of the former Jeroným Mine in Čistá these are old mine workings (SDD) of the ore mine (tin, tungsten), whose history dates back to the 15th century (termination of active mining activities in 1941 and survey completion in the years 1964-1966). At present, two separate areas are mapped at the deposit, for which the designations “SDD” (in the northwest) and “ODD” (in the southeast - in the area of the Jeroným pit) are commonly used. Although the designation is incorrect in terms of current legislation, we adhere in this article to the above mentioned classical denotation due to explicitness and possibility of comparison with previous works and map bases.

We note that even for accumulated ground water in the SDD of the Jeroným Mine, the term “mine water” cannot be strictly and legally correctly used (in the meaning of Article 40(1) of Act No. 44/1988, the Mining Act, and its amendments) - however, we will refer to “mine water” in this text as the focus of the article only concerns the fields of natural sciences (geology, hydrogeology, geochemistry, hydrogeochemistry, etc.) and gives no legal basis for economic and legal decisions related to this type of ground water.

## 2 DEPOSIT GEOLOGY

The former Jeroným Mine is now a system of old mine workings related to other mine complexes of unknown extent (except the mapped mine workings, the existence of further historical ones whose extent is unknown, cannot be excluded).

From a geological point of view, this is a complex of metamorphic rocks of Proterozoic age, creating an isolated block in the southern part of the Karlovy Vary granite massif. An important role of the metamorphosis was played by the so-called greisenisation, during which feldspars of original granite were completely replaced by quartz and topaz and when vein contributions of tin-tungsten mineralization (quartz-wolframite-cassiterite) occurred. The tin deposit of the former Jeroným Mine is bound to a smaller veining stock of Krušné hory binary granite and its mineralization can be localized in a small depth below the surface, where also historical breasts of the largest extent are situated. Endocontact, tin-mineralized zones and quartz veins with cassiterite were mined predominantly. The veins showed sharp contacts as a rule. The main veins were characterized by a large number of apophyses (offshoots). Ore lenses were distributed quite unevenly in the area of the veins and significantly clustered in elongated ore bodies.

The block is mostly composed of coarse grained biotite orthogneisses and paragneiss series, with predominance of biotite paragneisses with layers of amphibolites, quartzites and erlan. Younger dislocations and fissure systems in the "hard rocks" are then the main communication routes of ground water in the anthropogenically undisturbed rock environment.

By a qualified estimate, total 500 to 700 tons of tin was mined out in the locality. The metal content in ore only ranged from about 0.2 to 0.4 % of Sn, but with a very good yield of black sand. The mining area at the Jeroným deposit in Čistá has never been determined officially. The deposit is located in the Protected Deposit Area in Horní Slavkov, established in 1975, and whose stock of Sn-W ores was written off in the form of exemption from registration.

## 3 BASIN CHARACTERISTICS

The entire ore-bearing district is located in the territorial unit of Slavkovský les (nature reserve). The Slavkovský les territorial unit ($I_3$C-1) belongs to the Krusne hory sub-province (I3) and to the area of Karlovarska vrchovina ($I_3$C). The unit has the character of a large upland, herewith that the forests represent up to 50 % of the basin.

The deposit area of the former Jeroným Mine is located in the basin No. 1-13-01 (Ohře nad Teplou) in a hydrological order 1-13-01-127 (Lobezský stream) - the basin of the III order with an area of 39.48 $km^2$, where long-term annual rainfall is 769 mm, annual surface runoff is 304 mm, specific runoff is 9.63 $l.s^{-1}.km^{-2}$ [1]. The infiltration into the old mine workings is approximately 0.5 $l.s^{-1}$ [3] and evapotranspiration is about 465 mm per year. The slopes of the stream valleys are covered by deluvial deposits in a thickness of 2-3 m; there are about 10 to 15 m of thick alluvia (interstitial permeability) in the valley of water courses. The drainage base is formed by the Chalupecký stream and a nameless water course in the north (both are right-hand tributaries of the Lobezský stream).

At the deposit of Sn-W ores of the former Jeroným Mine, historical manifestations of mining activities are already seen in a near-surface zone (old mines, old collapses, cut rifts over breasts, distortions of room fenders by recent tectonics, weathering of room sides and falling-off of ceilings in mine workings, etc.). Except the mapped mine workings, other manifestations of historical mine workings whose extent is unknown, cannot be excluded. It can be said that the area affected by mining activities has a high potential of surface water infiltration into old workings. In the areas denoted as "SDD" and "ODD" of the former Jeroným Mine a relatively stable depression cone was created, which affects the regime of surface and ground water in wide surroundings.

## 4 DEPOSIT HYDROGEOLOGY

Assessing the hydrogeology of a mined deposit requires to know the system of opening, mining and possible disposal of old mine workings of the mine. The deep tin mining was applied at the deposit using shallow manholes with subsequent piping of cassiterite from rocks in the nearby stream. The ore was mined also through the Jeroným sough. The main mining method was the so-called "fire-setting", during which relatively large mining areas - chambers - originated. Apparently the mine workings did not exceed a vertical depth of 50 meters.


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In 70-ies and 90-ies years of the last century, collapses occurred in the Jeroným drift, which affected the gravity drainage of mine water, given by the old mine workings. The collapses occurred in about 130 m from the mouth of input manhole. There was fear of potential threat to the areas of this national cultural mining monument, and therefore the mine workings were made accessible in 90s by repairing the manhole of the former mine. The repairing of the Jeroným sough was performed in 2006.

From a hydrogeological point of view, the deposit rocks are low permeable, and in contact with ground water are relatively chemically stable. The permeability of crystalline complex (outside the weathering zone) depends on the density, opening and filling of fissures. The crystalline complex is classified at the level of impermeable rocks $K= 0.5 \cdot 10^{-9}$ $m.s^{-1}$ to $0.5 \cdot 10^{-10}$ $m.s^{-1}$. Most of tectonic structures of the deposit have low permeability ($K= 0.5 \cdot 10^{-6}$ $m.s^{-1}$) in general.

The greatest permeability (interstitial) is attained on the boundary of "weathered rock mantle - rock" - generally at a depth of 3-4 m; in the valley of streams and watercourses, the depth is 7-8 m. A deeper weathering zone reaches a depth of 10 to 12 m.

## 4.1 Ground water circulation

Currently, in the area of the former Jeroným Mine, three types of ground water circulation can be set apart:

- Ground water with a shallow circulation (partly communicating with the Chalupecký stream). This is the water bound to superficial deposits and supplied mainly from precipitation. The water table is free and follows the terrain in a conformal way. The depth of shallow circulation is conditioned by morphology and near-surface geological structure. The main infiltration of water underground takes place in locations of mining (currently, in the location of mining works filled by waste materials after the partial reclamation). After the flooding of the mine, part of the water is drawn down to the so-called drift level (i.e. the level of the Jeroným sough).

- Ground water accumulated in mine workings of the former Jeroným Mine situated above the level of the Jeroným sough drainage base (i.e. above the level of +735 m above sea level). The entire mining field is not likely flooded to the level of the Jeroným sough only, but the local erosion base level will probably be lower, because the operation level, e.g. at the drift level in the V3-V4 area, shows an even lower level of drainage. This state is possible due to lack of knowledge of all mining openings of the deposit in the deep past.

- Ground water with a deeper circulation is bound to more permeable sections of tectonic structures of deposit rocks, i.e. sections where the extraction took place. The mine water together with the overflow of water from a shallow aquifer and mine workings, producing the accumulation of water in the so-called suspended aquifer, is drained by the Jeroným sough (about +730 m above seal level) or possibly by mine workings at a lower level (currently unknown/unrecognised deeper drainage bases) into surface water.

## 4.2 Hydrochemical analysis of mine water

In many ore-bearing localities in the Czech Republic, waste water was not treated after completing the extraction and it was necessary, at least temporarily, to keep the water table in the mining field by pumping at a set spot elevation. The reason was to prevent the infiltration of mine water into surface water of a near watercourse, or reservoir, preventing uncontrolled outbursts in terrain, outflows of contaminated mine water from drifts, overflows from chimneys and boreholes, etc. In the case of the former Jeroným Mine in Čistá it is a simple discharge from the portal of the drift. Between the years 2007 and 2009, the VSB-TU Ostrava made mine water sampling and advanced hydrochemical analyses [6] and [7]. The results are shown in the following table.

**Tab. 1:** *The results of hydrochemical analyses of the years 2007 and 2009*

| | | Kvalita důlních vod ložiska : Jeroným v Čisté | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Lokalita: | bývalý důl Jeroným | | | (údaje v $mg.l^{-1}$ - pokud není uvedeno jinak) | | | | |
| účelové vzorkování 2007 | | pH [--] | RL | NL | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $Fe^{2+}$ |
| | K1 | 6,65 | 121 | 5,61 | 14,10 | 5,61 | 8,87 | 2,57 | 0,07 |
| | K2 (V3) | 6,13 | 105 | 11,00 | 9,13 | 3,65 | 5,57 | 1,96 | 0,03 |
| | | vodivost [mS/m] | $SO_4^{2-}$ | $Cl^-$ | $NO_3^-$ | $NO_2^-$ | $F^-$ | $PO_4^{3-}$ | $Mn^{2+}$ |
| | K1 | 19,00 | 42,00 | 13,00 | 18,00 | | 7,00 | 5,00 | |
| | K2 (V3) | 12,40 | 24,00 | 10,00 | 9,00 | 0,20 | 1,90 | | |
| | | Al | B | Ba | Be | Br | Li | Pb | Zn |
| | K1 | 0,260 | 0,024 | 0,048 | 0,001 | | 0,048 | 0,014 | 0,054 |
| | K2 (V3) | 0,358 | 0,153 | 0,014 | 0,001 | 0,3 | 0,009 | 0,033 | 0,097 |
| účelové vzorkování 2009 | | pH [--] | RL | NL | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | Zn |
| | V1 | 9,18 | 138 | 0,2 | 13,20 | 4,86 | 10,50 | 3,02 | |
| | V2 | 6,89 | 143 | 1,3 | 13,80 | 5,35 | 8,96 | 2,42 | |
| | V3 | 6,00 | 76 | 0,2 | 7,06 | 3,18 | 4,98 | 1,89 | |
| | V4 | 5,76 | 72 | 5,90 | 5,47 | 1,58 | 2,31 | 1,66 | 0,18 |
| | | vodivost [mS/m] | $SO_4^{2-}$ | $Cl^-$ | $NO_3^-$ | $F^-$ | Al | B | Li |
| | V1 | 19,70 | 35,00 | 16,10 | 8,07 | 0,15 | 0,09 | 0,61 | 0,11 |
| | V2 | 70,00 | 44,00 | 11,10 | 10,30 | 0,26 | 0,14 | 0,31 | 0,12 |
| | V3 | 12,70 | 23,00 | 7,15 | 5,41 | 0,14 | 0,33 | 0,13 | 0,12 |
| | V4 | 9,15 | 13,20 | 2,44 | 6,25 | 0,80 | 0,56 | 0,05 | 0,13 |
| | | **Poznámka** | neuváděny hodnoty u parametrů s obsahy pod mezí detekce (např. As, Fe, Se, Sb, Sn, Mn, Co, Cu, Cd aj.) | | | | | | |

Legend to the table:

K1 .... flooded mine area at Můstek in the K1 chamber,
K2 (V3) .... K2 chamber - the supply point at the end of the CH42 gallery at the drift level,
V1 .... supply point above the K1 chamber level,
V2 .... supply point at Můstek in the K2 chamber,
V4 .... supply point in the gallery parallel to the gallery at the drift level (V3).

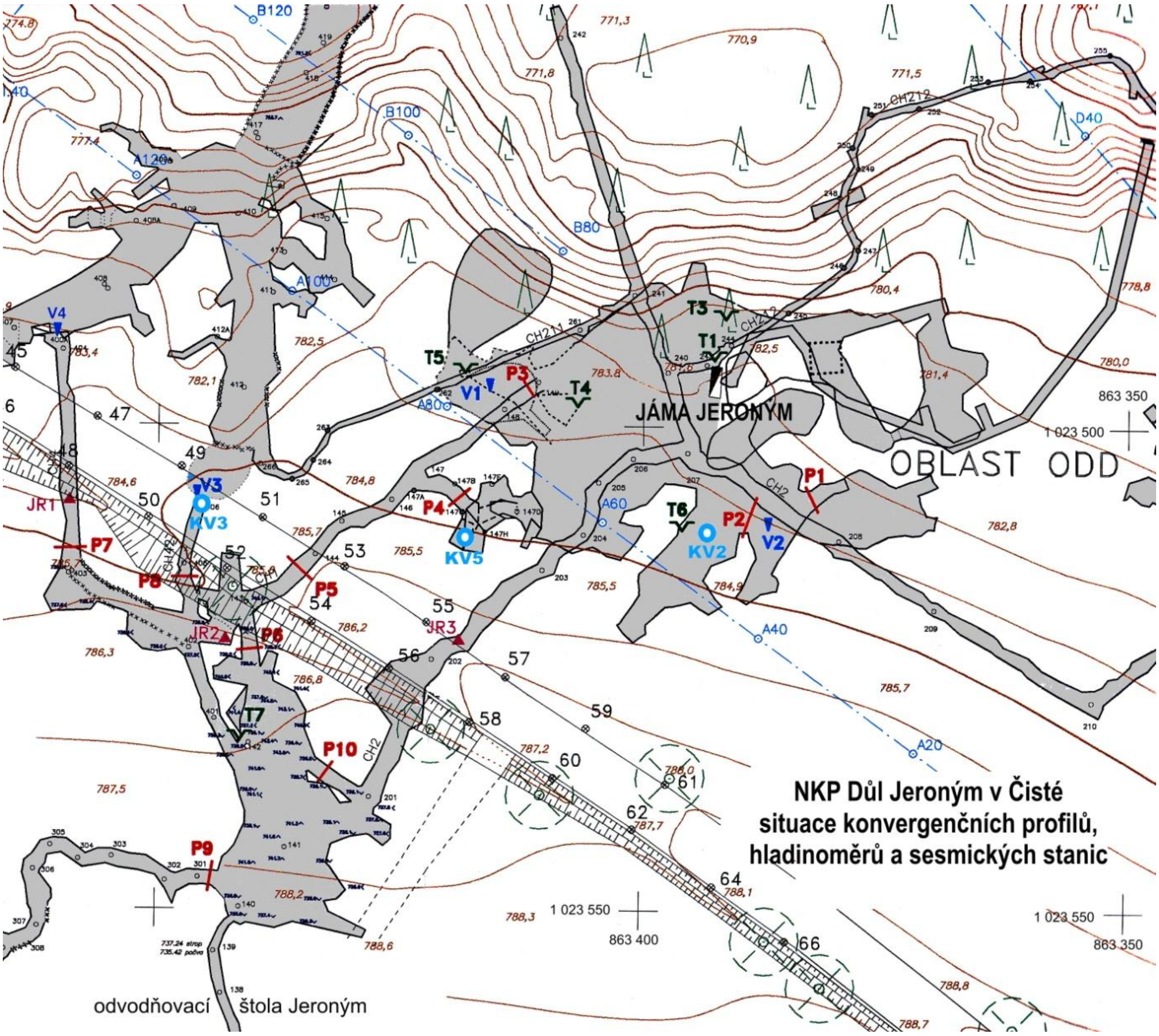



**Fig. 1:** *Distribution of level gauges in the Jeroným Mine (blue colour)*

## 4.3 Hydrochemical analysis of mine waters

Next mining hydrogeochemical analyses of mine water (see table below) were performed within systematic monitoring, conducted by s.p. DIAMO Straz p. Ralskem as an enterprise, which took over all the old and abandoned mines in the Czech Republic. The mine water at a former Jeroným Mine in Čistá was, according to the decision of the Regional Office in the Karlovy Vary Region, the environmental department, ref. 2618/ZZ/06 dated November 27, 2006 (valid until December 31, 2011), discharged without treatment into the watercourse of the Chalupecký stream herewith that the water will meet the limits and conditions set out by the above cited decision of KUK. An extended analysis of mine water in two-year intervals was then required.

In the period of the years 2002-2007, the following values were attained: pH= 6.9-9.0; NL= -9.0 $mg.l^{-1}$; Fe = 0.2-2.4 $mg.l^{-1}$; Zn = 0.01– 0.06 $mg.l^{-1}$.

All analyses of mine water at the former Jeroným Mine show that exceeding the specified limits took place sporadically and accidentally only (e.g. in 2008, just a single parameter exceeded, in particular for Fe [4]; in 2009 just a single parameter exceeded, in particular for NL [5]). The monitored indicators met even the limits set by Government Order No. 61/2003 Coll., or its amendment No. 229/2007 Coll. (Tab. 2). Any negative effect on the environment hydrosphere of the former mining area at the Jeroným Mine caused by discharges of mine water to the surface do not occur, and the current hydrogeochemical regime is stabilized.

**Tab. 2:** *Comparative table of set and actual parameters of the discharged water quality*

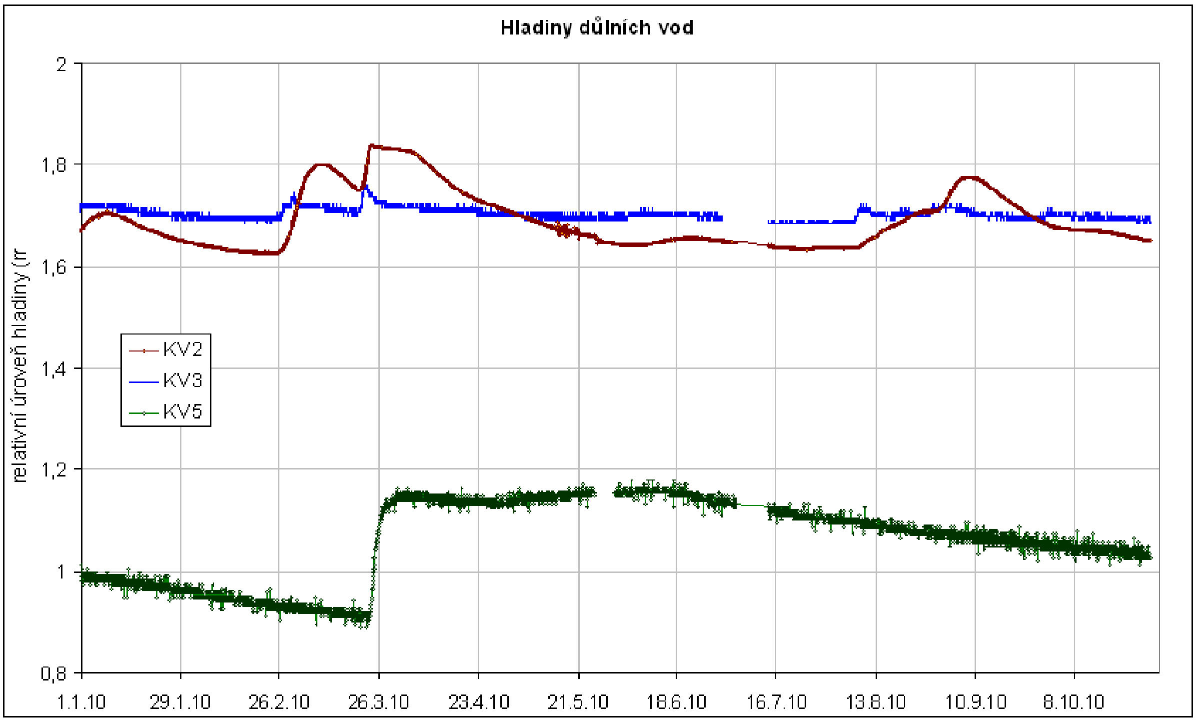
| Kvalita vypouštěných vod do vod povrchových : důl Jeronym v Čisté | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Lokalita : výpustný profil - výtok ze štoly Jeroným** | | | | | | | | |
| **Stanovené parametry:** | | | | **Dosažená skutečnost - 2008** | | | | |
| **Ukazatel** | **Hodnota** | **Jednotka** | **Bilanční hodnota** | **Min.** | **Max.** | **Prům.** | **Bilanční hodnota** | **Jednotka** |
| $Q_{rok}$ | Ø = 3<br>max.= 10 | [l.s$^{-1}$] | 94 608 | 0,46 | 19,7 | 6,78 | 213 814 | [m$^3$.rok$^{-1}$] |
| NL | "p" = 20<br>"m" = 40 | [mg.l$^{-1}$] | 1,89 | 2 | 4 | 3 | 0,641 | [t.rok$^{-1}$] |
| $Fe_{celk}$ | p = 2<br>"m" = 3 | | 0,189 | 0,08 | 2,76 | 0,85 | 0,181 | |
| pH | 6,9 | - | - | 7,1 | 8,1 | 7,6 | | |
| **Stanovené parametry:** | | | | **Dosažená skutečnost - 2009** | | | | |
| **Ukazatel** | **Hodnota** | **Jednotka** | **Bilanční hodnota** | **Min.** | **Max.** | **Prům.** | **Bilanční hodnota** | **Jednotka** |
| $Q_{rok}$ | Ø = 3<br>max.= 10 | [l.s$^{-1}$] | 94 608 | 0,27 | 3,98 | 1,59 | 50 142 | [m$^3$.rok$^{-1}$] |
| NL | "p" = 20<br>"m" = 40 | [mg.l$^{-1}$] | 1,89 | 2 | 8 | 4 | 0,2 | [t.rok$^{-1}$] |
| $Fe_{celk}$ | p = 2<br>"m" = 3 | | 0,189 | 0,15 | 1,13 | 0,53 | 0,027 | |
| As | - | | - | | 0,018 | | 0,0009 | |
| $Fe_{celk}$ | - | | - | 0,01 | 0,06 | 0,04 | 0,02 | |
| Cu | - | | - | | 0,003 | | 0,00015 | |
| $N\text{-}NO_3$ | - | | - | | 1,3 | | 0,0652 | |
| N-NH4 | - | | - | | 0,5 | | 0,0251 | |
| $SO_4^{2-}$ | - | | - | | 26,0 | | 1,304 | |
| Pb | - | | - | | 0,005 | | 0,00025 | |
| Sn | - | | - | | 0,02 | | 0,001 | |
| Zn | - | | - | | 0,02 | | 0,001 | |
| NEL | - | | - | | 0,1 | | 0,005 | |
| pH | 6,9 | - | - | 6,6 | 7,5 | 7,1 | | |

In November 2009, the former Jeroným Mine was passed to the state enterprise DIAMO Stráž p. Ralskem by the Regional Office in the Karlovy Vary Region.

## 4.4 Dye penetrant experiment

The former Jeroným Mine consists of an underground system of tunnels partly hydraulically interconnected and non-interconnected (the area of "SDD"), both open by the Jeroným pit (at the spot elevation of about +783 m) and by drifts. Due to the age of openings and breasts at the deposit, their complete mapping and understanding may not currently be guaranteed.

To confirm the assumption of interconnecting the areas "SDD" and "ODD", a dye penetrant experiment was carried out in 2006 by the company Stavební geologie – GEOTECHNIKA, a.s., Prague [2]. The penetrant was fluorescein applied to the lowest L chamber in the "SDD" area (in place of seepage of mine water into downstream, inaccessible mine workings). According to the protocol [2], the overflow into lower ground areas was approximately 0.5 l.s$^{-1}$ and the quantity of already accumulated mine water was about 900 m$^3$. After the retardation of about 30 hours the dye appeared "*in the spillway of sinking*" at the Jeroným sough in the "ODD" area. Thus the assumption of a hydraulic interconnection between the two areas, i.e. “SDD” and “ODD”, was confirmed.



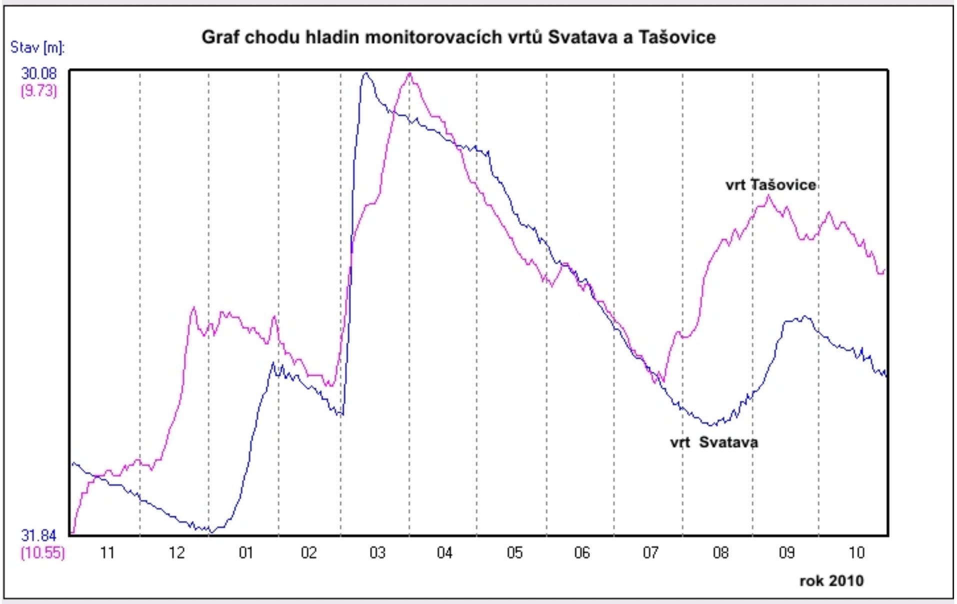
**Graph 1:** *The development of water tables at KV2, KV3 and KV5 sites*

Within the monitoring of the stability of mine workings, changes in levels of the flooded mine workings in the “ODD” area were tracked in 2010 [8]. The development of water tables at KV2, KV3 and KV5 sites is shown in the following graph.

A significant increase in levels, as is evident from the graph of water tables in old mine workings, occurred virtually in all monitored areas of the mine in March 2010. The causes of this phenomenon are difficult to explain due to the complexity and considerable ignorance of actual priority roads, consisting of old mine workings and breasts. There are three real reasons as follows:

- meteorological situation prior to the observed phenomenon - the phenomenon would significantly correlate with the course of rainfall, melting snow, flow rate of flood waves, etc.,
- overflow siphon effect from higher levels of the mine (from the suspended aquifers along so far unseen old mine workings) - the phenomenon would be considerably of a periodic character,
- overflow from higher levels of the mine (from the suspended aquifers along so far unseen old mine workings) after overcoming the hydraulic resistance (and subsequent loosening) of clayey sediments accumulated in the mine working - the phenomenon would be substantially of an accidental character.

After consultating the CHMI (Pilsen branch, Ing. J. Glanc), the most likely cause of the jump increase in water table of the flooded mine workings is in this case the current meteorological situation in a wider area of the deposit. A significant rise of ground water tables was observed at that time in monitoring boreholes of the CHMI network. The increases were measured even in neighbouring hydrogeological zones and especially on objects in the Sokolov Basin (see, e.g. the groundwater-level depths in boreholes in the villages of Svatava (Sokolov) and Tašovice (Karlovy Vary). Legitimacy of the hypothesis is also supported by the subsequent rise in water tables in the 7th month of the year 2010, to which the water table in KV2 responded.




The cause of the significant change in mine water tables in March 2010 was most likely a seasonal meteorological event in the last decade of February 2010, when the weather significantly got warmer and much of a high snow cover melted (compared to the half of the month the supply of water in snow was one-third at the end of February). The effect of rainfall was minimal at that time. According to a statement of CHMI, water table increases due to weather changes in the Lobezský stream area were more pronounced in boreholes and springs that monitored deeper aquifers.

## 5 CONCLUSIONS

The Jeroným Mine in the village of Čistá is registered as a cultural monument in the Central List of Immovable Cultural Monuments.

Endocontact tin-mineralized zones and quartz veins with cassiterite were the subject of mining at the turn of the 15th and the 16th centuries. The biggest mining boom occurred in the 16th century, and then the mining proceeded sporadically in the 17th and 18th centuries. The underground tin mining was performed through shallow internal manholes with subsequent piping of cassiterite from rocks in a nearby stream. The ore was mined also through a drainage gallery.

In 1990, the Jeroným Mine was declared by the Ministry of Culture as the state-protected cultural monument, and was written into the national register of cultural monuments. Currently, works are underway on making the mine public in the form of a mining open-air museum within the Georgia Agricola Foundation.

Within the activities, the staff of the VSB-Technical University of Ostrava (Faculty of Mining and Geology and Faculty of Construction), the Institute of Geonics AS CR and employees of the state enterprise DIAMO carry out the long-term monitoring of both hydrogeological regimes, and environmental problems associated with negative impacts of mining activities on the environment (impacts of undermining - ensuring the stability of surface, geomechanical stability of underground rock massif - seismic, geological, geophysical and geomechanical monitoring).

This article deals primarily with hydrological and hydrogeological aspects. Due to the collapse in the Jeroným sough the natural gravity discharge of mine water was disrupted and a potential threat to the cultural heritage by flooding occurred. Even an increased proportion of radon in mine air was documented [3]. The quantity of running out underground water to the surface is about 93 thousand $m^3$ per year [5]. The main observed quantities in the water are in addition to suspended solids and pH values also values of heavy metals (V, Fe, Zn, Mn, As, Cu and Pb). The existing mine water monitoring results of the former Jerome Mine show that the exceeding of specified limits was only of a sporadic and haphazard character, and that there is no threat to the environment hydrosphere.

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