Results of the WELLaHEAD Project connected to water and mining

Geothermal potential of the Tokaj-Mountains pilot test of passive acid mine drainage water management

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Abstract: The region of the Tokaj-Mountains can be found in North-East Hungary. Although there were some mineral prospecting projects in the 1960s and 1970s the regional water budget and the groundwater flow systems were not known before the complex hydrogeological investigations carried out in the framework. A special prospecting methodology involving geological, hydrogeological and surface geophysical methods was also elaborated as an asset to find thermal water resources in this special volcanic region.

The main goals with the disposal of limestone and lignite filling in a trench were reducing the high solute content and raising the pH to neutral direction respectively. Water chemistry analyzes performed during the test run time proved the legitimacy of technology, but further studies are needed in order to be able to reduce the negative effects during the operation.

1 Introduction

The Tokaj-Mountain is one of the most famous volcanic mountains of Hungary, located in the north-eastern part of Hungary, as part of the Carpathian Basin. Its strike is to the north-south, and approximately 100 - 120 km long. The mountain runs between Tokaj and Eperjes (Slovakia) (Kiss 2007). The thermal and geothermal researches in the Tokaj-Mountains always have secondary importance from the point of view of the hydrogeologists, due to its complex geological structure and the insufficient number of exploration deep-wells. In 2012 the University of Miskolc, Department of Hydrogeology and Engineering Geology has started a very detailed hydrogeological survey for the wells of the entire Northern Hungary. During our research we have observed that, despite of the complex geological structure many potential thermal aquifers can be found at the investigated area. The aims our research was to characterize with numerical methods the hydrological parameters of the thermal aquifers and geothermal gradient of the area.

2 Geological settings

We have impounded the investigated area mainly by natural boundaries. The boundary at North is the Hungarian-Slovak border, the western boundary runs along the Hernád-valley, which is a north-northeast south-southwest structural line, known also as the ALCAPA-Tisza tectonic line, a part of the Central-Hungarian lineament. The southern boundaries of the area are the Tisza and Sajó Rivers. Finally, the eastern borders are the Tisza and the Bodrog River. The geological structure of the Tokaj Mountains is very complicated and elaborated. The depth and the material of the basement are still in question. Although many of basement maps show that it is in approx. 1500-2000 m depth, and the material of the basement is probably metamorphic mica. Concerning the geological structure of the investigated area, proved by the thermal karst of Sárospatak and Bükk that the shallow marine carbonate sediments deposited to the research area in the Triassic. Neogene vulcanite formations settled to the basement materials with hundred or – in some places in – thousand meters of thickness. The reason of the extraordinary thickness is that the volcanism has started in the Miocene and ended in the Lower-Pannonian. The Pannonian Lake has gradually lost its salinity, and it has charge by the river-drift. The Upper Pannonian clastic sediments pinched-out on the southern part of the research area, but toward the Great Plains their thickness is increasing. In several areas, above the Pannonian layers Pleistocene fluvial sediments have settled in large thickness. At those areas the Holocene formations are negligible. Figure 1 shows the geological model of the Tokaj-Mountains.

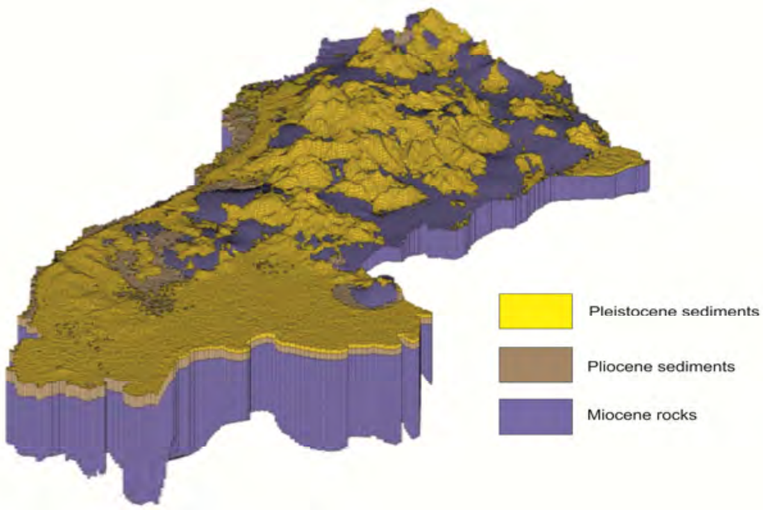

Fig. 1: Geological model of the Tokaj-Mountains

3 Hydrogeoligical and geothermal parameters

The layers of the Tokaj-Mountains have got different hydrogeological parameters. The Pleistocene and Pliocene sediments have a good hydraulic conductivity, and porosity, but it's shallow. The Miocene rocks are impermeable, and the water can flow only in the fractures, and faults. The inner part of the mountains is an infiltration area. The precipitation infiltrates and flows down through fractures to the edges of the mountain. In the edge of the mountains have two structural lines (Hernád and Bodrog lines), which through the water rises rapidly near the surface. Figure 2 shows the conceptual flow model of the Tokaj-Mountains.

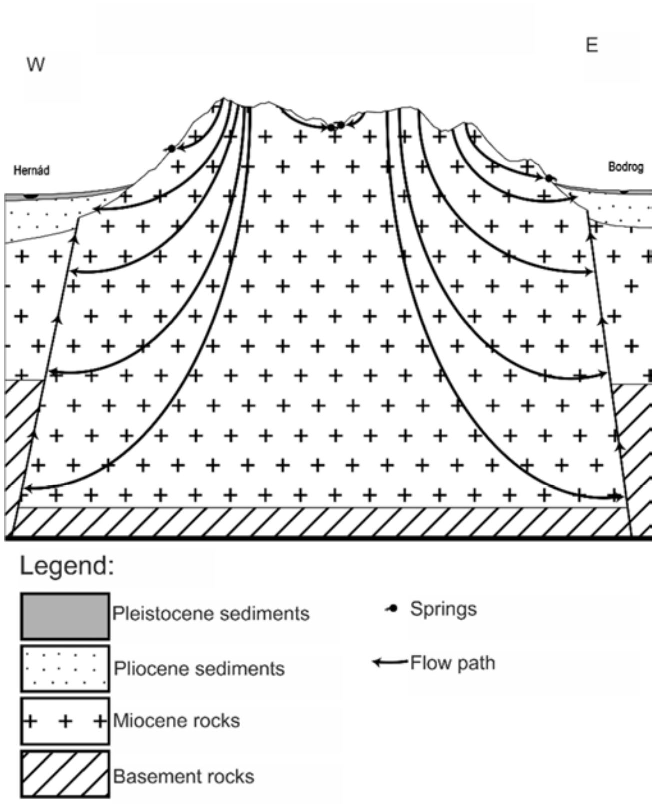

Fig. 2: Conceptual flow model of the Tokaj-Mountains

The edges of the mountain have got a lot of thermal and tepid water anomalies, in the guise of wells and springs. The outflow water temperature of the wells and springs have between 20-31 °C. The average geothermal gradient of Hungary is 5 °C / 100m, and the mean temperature in the country is 10 °C. So the deep of the flow path is approx. 200-400 m deep. This is the deep of the youngest lava rock. The tepid and thermal water anomalies designate a fracture, in north and south direction. The northernmost anomaly is located in Kéked, than to south: Pányok, Gönc, Korlát, Hernádcéce, Abaújszántó, Boldogkőváralja, Bekecs, and then Szerencs. Table 1 shows the screening depth and the outflow water temperature of the tepid water anomalies (Szófogadó 1961).

Tab. 1: The tepid water anomalies on the Kéked-Szerencs tectonic line

Name	*Screening depth [m]*	**Outflow water temperature [˚C]**
Kéked	spring	20
Pányok	28	31
Gönc	spring	20
Korlát	31	26
Hernádcéce	302,5	24
Abaújszántó	39	22
Boldogkőváralja	178	24
Bekecs	60	21
Szerencs	202	26

The highest temperature was measured in Pányok (31 °C), which is the highest temperature ever in the mountains.

4 Thermal water in Pányok

Pányok lies in the northeastern slopes of the Tokaj Mountains, near the Hungarian-Slovakian border. It is traversed from east to west by the Hasdát creek and is bordered by the Nagy Hill from south, and the Tilalmas and Sátor Hills from east. The Hesdát creek also follows an E – W fault, together with the adjacent Lapis and Csenkő creeks. The tepid springs of Kéked emerge along the fault of the Lápis creek (Figure 3.)

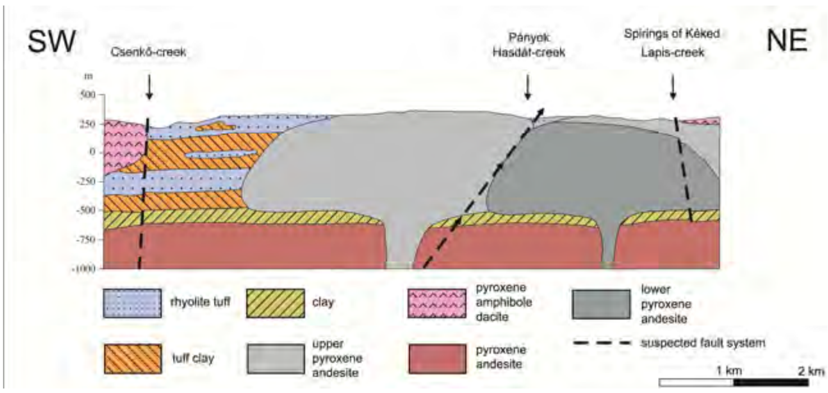

Fig. 3: The fracture system of Kéked and Pányok

The surface morphology of the studied area has a significant influence on the groundwater flow. Besides the primary porosity, depending on petrographic factors, the hydraulic conductivity and storage is affected by the presence and quality of fractured zones. Recharge from precipitation occurs mostly through the rhyolitic tuffs and the andesite, both characterized with reduced conductivity. As a result the recharge is very limited. Another factor affecting the flow system is the hydrothermal alteration and weathering, forming impermeable clayey lens and silicified zones. The majority of the wells found in the zone are shallow (below 20 m) and are providing cold water (10 – 12°C). The chemical composition reflects the geologic settings: low dissolved solid content and relatively high sulfate concentration. Two of the wells found in the village, show an outstandingly high apparent geothermal gradient (250 °C/100 m), with almost the highest water temperatures across the whole mountain. The well No 1 lies in the northeastern part of the village. It is screened between 26 and 28 m, where the bottomhole temperature is 33°C and provides an outflow temperature of 31°C. The well No 2 is located 100 m north from the well No 1. It is screened at the depth of 40 m and provides an outflow temperature of 28°C. On the basis of the water quality of the wells and the geologic aspects, a NW – SE trending fault may be assumed, through which significant upward flow occurs (Figure 4.)

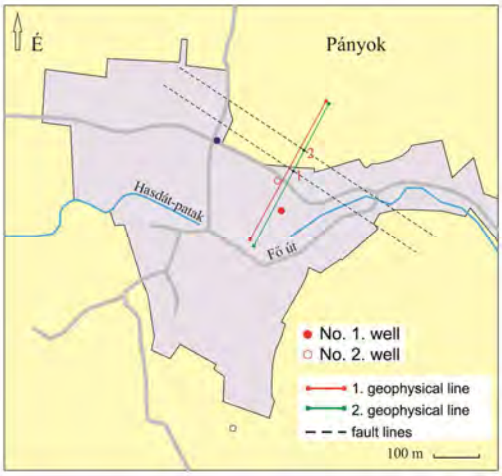

Fig. 4: Fracture system in Pányok

The location and water quality of the wells, as well as the local geomorphology, suggested the presence of a fault with a roughly NW – SE strike. In order to gain a detailed image, multi electrode resistivity measurement had been carried out. This method is similar to the vertical electrical sounding, except both the power and the measuring electrodes are moved successively over the whole array. The measurements had been carried out through two parallel profiles, perpendicular to the supposed fault (Figure 4.). Based on the processed resistivity profile (Figure 5.) and the geologic and structural information, a conceptual geologic model had been proposed. The wells are resupplied through a boundary fault of a buried horst. On the basis of the water temperatures and the geothermal gradient of the area a flow path of about 400 m depth may be assumed. The water age of the collected samples is 15 000 years. The conceptual model of the flow system is presented on Figure 6. The recharge area is located in the internal and higher parts of the Tokaj-Mountains. Water moves through fractures and is forced upward near the borders of the mountain through the faults revealed by electric surveying.

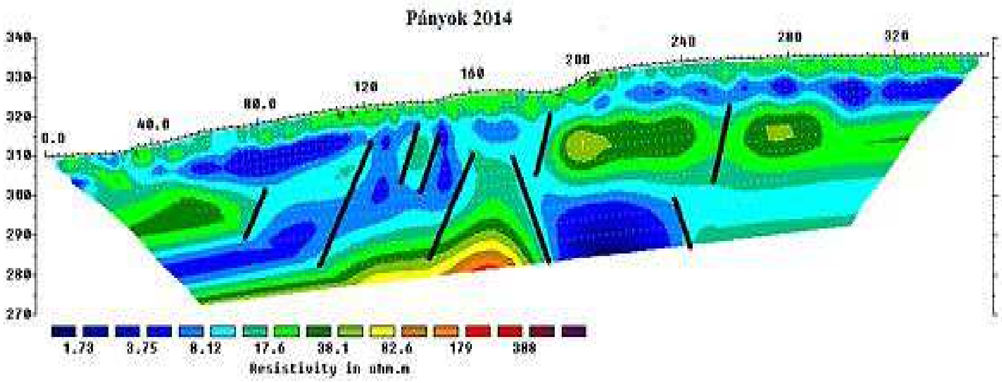

Fig. 5: The NE-SW multielectrode resistivity profile in Pányok (Fejes et al. 2015)

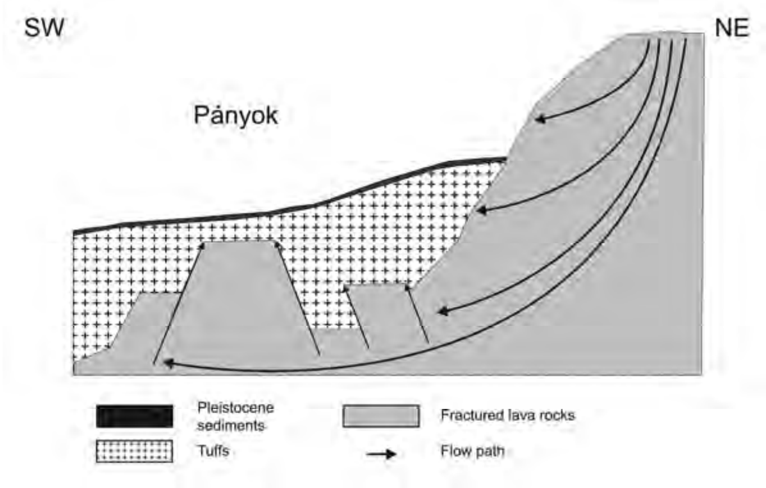

Fig. 6: Conceptual flow model of the Tokaj-Mountains

5 Passive AMD treatment technology – pilot test

One of Northern Hungary's abandoned ore mine is under a complex rehabilitation program, which involves the passive acid mine drainage treatment pilot site at one of the former mine shaft. The effluent water is characterized by acidic pH level ranging between 2-4 and high dissolved metal contents Fe(II) concentration varying from 589-914 mg/dm^3, Cu concentration ranging up to 30 mg/dm3. The discharge is moderate, ranging between 1,5-2,5 m^3/nap, but even with the limited discharge it causing significant environmental load in the area. The operator of the site decided to develop a passive treatment technology and our research team offered a feasible technology as a test operation. The designed technology was based on former research of using lignite as a reactive barrier material (Bőhm et al. 2003) (Madarász et al. 2011.) and on preliminary lab measurements of both the hydraulic parameters and chemical functionality of the applied materials. For the adsorption of high heavy metal content of the drainage lignite reactive material was applied. Literature studies showed, that lignite has favorable properties and its adsorption capacity can reach up to 30% to that of active coal [Lakatos et al 2009] while its cost is one order of magnitude lower, also the expensive regeneration costs can be eliminated if the exhausted lignite material is reused. After testing several options the team concluded that the grain size of 11-22 mm is appropriate to meet the hydraulic demand on the site test. A 56 m long concrete test channel was installed at the site which was separated to three cascades to support the treatment technology steps. The technology consisted of 3 successive steps: 1. step: 40m long neutralization section filled with limestone (11-22 mm); 2. step: 8 m long section of 1:1 mixture of limestone and lignite (11-22 mm); 3. step: 8 m long lignite field for adsorption of dissolved metals (Figure 7 and 8). During installation of the on site test operation deflector walls were placed in the channel to increase the interaction time between the drainage and reactive material.

Fig. 7: Materials used in the passive AMD treatment pilot test (a (both pictures on the left side), grounded limestone and grounded lignite; b (right picture), mixture of the grounded materials)

Fig. 8: Installing the passive AMD treatment channel

The performance of the treatment technology was monitored by installing sampling points and on site passive samplers at various points of the technology and in the discharging stream. Water samples were analyzed in laboratory for the relevant metal content of the drainage water (Al, Fe, Cu, Ca, Mg, Zn, Ni, Pb, As, Cd). Table 2 and Figure 9 shows the change of iron and copper concentration at two sampling time and four sampling points along the technology.

Tab. 2: Summary of lab results for Fe (II) and Cu

Sampling point along the technology canal [m]	Time of sampling			
	2013.10.22		2013.11.15	
	Concentration of Cu [mg/l]	Concentration of Fe(II) [mg/l]	Concentration of Cu [mg/l]	Concentration of Fe(II) [mg/l]
0+000	21.65	1098.5	20.65	1039.5
0+040	20.55	816.5	21.5	1033.5
0+048	-	-	17.55	748.5
0+056,5	3.65	555.5	18.6	742.5

The obtained results prove the decreasing concentration of both components along the treatment channel. The concentration of iron decreases through the full length of the channel, while in case of cupper only the last lignite based section was effective.

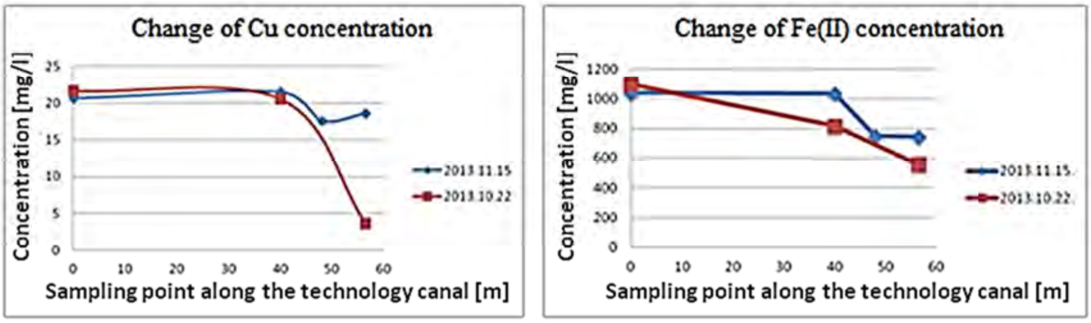

Fig. 9: The change of Fe (II) and Cu concentration along the channel in two testing time

The background for this phenomena is due to the increase of pH causing Fe(II) being transformed and precipitated as Fe(III) already in the first half of the treatment channel. In the second half adsorption can further decrease the concentration due to the lignite barrier. The change in trends between the two time periods is due to decreased performance of the treatment technology barrier. Several factors contribute to the decreasing efficiency. As Fe (III) precipitates on the surface of limestone a crust is formulated blocking the neutralizing effect of the material. This has an impact on the adsorption capacity, as the acidic pH is not ideal for the adsorption on lignite. The described crust formulation has a negative effect on the hydraulics of the whole system as well, although it did not cause any problem at this stage of the test operation. The team had to conclude that the neutralization of the AMD discharge must be implemented with other mechanism, which is shifting the study into a new line of research.

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