REMEDIATION OF THE FORMER LEAD-ZINC ORE MINE AND THE MINE WATER TREATMENT ON THE SITE (GYÖNGYÖSOROSZI, HUNGARY)

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Abstract
In the northern part of Hungary in Mátra-Mountains non-ferrous metal ore mining lasted through centuries up to 1986. Initially gold and silver, then lead and silver, and finally in the XXth century lead and zinc were the target metals. Nevertheless the real industrial-scale mining lasted only in the period 1950-1986 when mining ceased. From that time only mine water treatment has been carrying out.
In this paper a general overview of the planned remediation of the site is presented. Detailed data are presented on reconstruction of the mine water treatment plant.

Introduction
The maximum yearly output of the ore was 150-200 kt. The ore was upgraded on site by flotation processing. Total production amounted to 3.4 Mt, from which zinc-lead ore concentrate and pyrite were removed and sold. Mining activity was terminated in 1986 because of the high production cost. From that time mine has been in stand-by, and practically, the only remediation action has been the treatment of mine water. In 2004, it was decided to carry out overall remediation of the former site, including 23 waste rock piles, the flotation tailings pile and the contaminated receiver creek, called *Toka-creak,* together with the water reservoirs located downstream. Because the water treatment issues are important during the remediation, it was decided to reconstruct the old water treatment plant. This work was undertaken in 2006 and practically has been completed. A cross-section of the three main mining fields (veins) is presented in Figure 1.

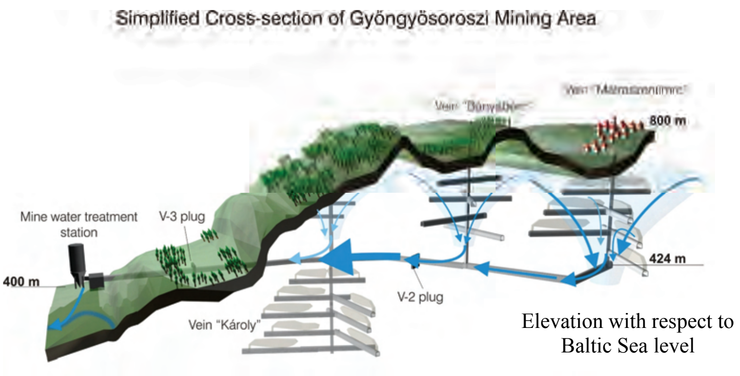

Figure 1. Simplified cross-section of the Gyöngyösoroszi mining fields (three groups of veins).

The adit links the three principal mining fields. The biggest of them is the vein "Károly", which has been totally flooded after termination of the mining. The two others are located at higher altitude, so they are in part under permanent dewatering and influenced by the atmosphere.

Remediation strategy
Altogether 38 waste rock piles are mentioned in technical and historical literature on the site; many of them refer to the XIXth century or even earlier. According to the risk analysis, 23 waste rock piles should be remediated (total volume is about 45,000 m^3); six of them have to be relocated on the top of the flotation tailings pile. Contaminated soil from cleanup of the area also will be placed on the flotation tailings pile.
An air view of the flotation tailings pile can be seen in Figure 2.
Detailed investigation of the tailings (among others in the frame of EU-tailsafe project in 2002-2005) led to the conclusion that the tailings are acid-producing having 30 kg $CaCO_3$/t net acid generation potential. But at the same time the pH of pore water inside the pile is in the range of 7-8, though in some spots in the upper layers it is lower, likely because of the oxidation processes. In any case, the seepage from the pile is neutral. The planned remediation of the tailings pile started recently; it includes stabilization of the dams, and weak surfaces,

dewatering, recontouring, and multi-layer covering of the tailings; the latter comprises a clay layer on the top and lime at bottom for buffering the pH of the percolating water.
The volume of mine water nowadays ranges from 2500 to 6000 m^3/d depending on the seasons. Mine water treatment needs to be continued at least in the near future, because of the heavy metal content. Since the water treatment station was built almost 30 years ago, and taking into account its importance during remediation, it was decided to reconstruct the station with a more efficient plant.

Figure 2. Tailings pile with free water on the top.

The underground workings in the "Mátraszentimre" field are subjected to backfilling with fly ash thick pulp. It was determined by lab tests that the fly ash has no adverse effect on the mine water chemistry; moreover it removes some pollutants (e.g. Zn, Cd, As, Fe) from the water. Since the sediments in the *Toka-creak* have elevated concentrations of heavy metals, the floodplain must be cleaned up.

Mine water chemistry

Prior to deal with the mine water treatment issues it should be mentioned that a plug, a concrete barrier (V-2 plug in Fig. 1), was built in the main adit in October 1987, aiming at flooding the highly pyritic mining field (vein "Mátraszentimre") for stopping the oxidation process there. But after some months of operation, under the huge pressure of water during rebound, the barrier and the rocks in its immediate vicinity were seriously damaged. In August 1988 the accumulated highly contaminated mine water escaped through the mine adit causing serious contamination of the receiver *Toka-creak.* So the plugging experiment has failed. It is worth mentioning that a rapid change of the water quality in the plugged mine was observed. These data are presented in Table 1.

Table 1. Water chemistry changing in plugged mine (Mátraszentimre, 1988).

Date	pH	Zn mg/L	Mn mg/L	Fe mg/L	TDS mg/L
08.01.1988	3.55	31	13	71	2025
15.01.1988	3.2	28,5	13	71	2001
07.03.1988	3.25	674	40	2421	17320
16.03.1988	3.2	652	63	3016	21464
30.03.1988	3.05	979	46	1848	20015
13.04.1988	3	910	60	1993	22631
28.04.1988	3.15	1142	70	2274	22569
11.05.1988	3.2	1064	65	3015	22649
01.06.1988	3.1	1087	81	3894	24322
28.06.1988	3.6	1130	67	3712	26914
22.07.1988	3.65	1178	75	2792	29227

It can be seen that the zinc, iron and manganese concentrations rose very quickly and the total dissolved solid (TDS) of water has achieved 29 g/L during 220 days working period of the barrier. The results point out that in closed mines affected by rebound the water can become very highly contaminated (Nordstrom, 2005). Therefore

the accumulation of water in the mine cavities (which are subjected to aeration) has to be avoided. One possible way to do this is the backfilling for decreasing the effective volume of the pit.
Change of the mine water quality over three decades (for the period of 1976-2006) is presented in Figures 3 and 4. The termination and the failed closing "experiment" are also indicated.

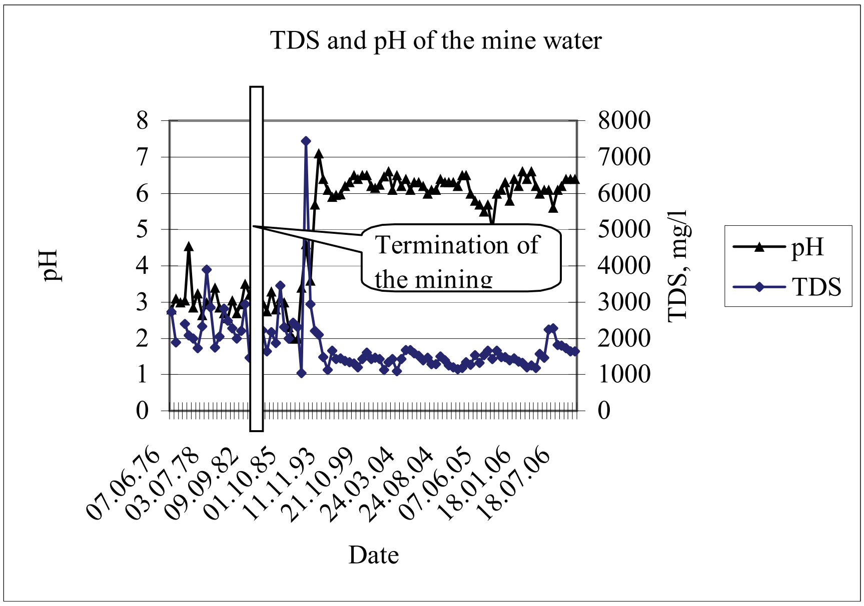

Figure 3. TDS and pH in the mine water during activity and after the mine closure.

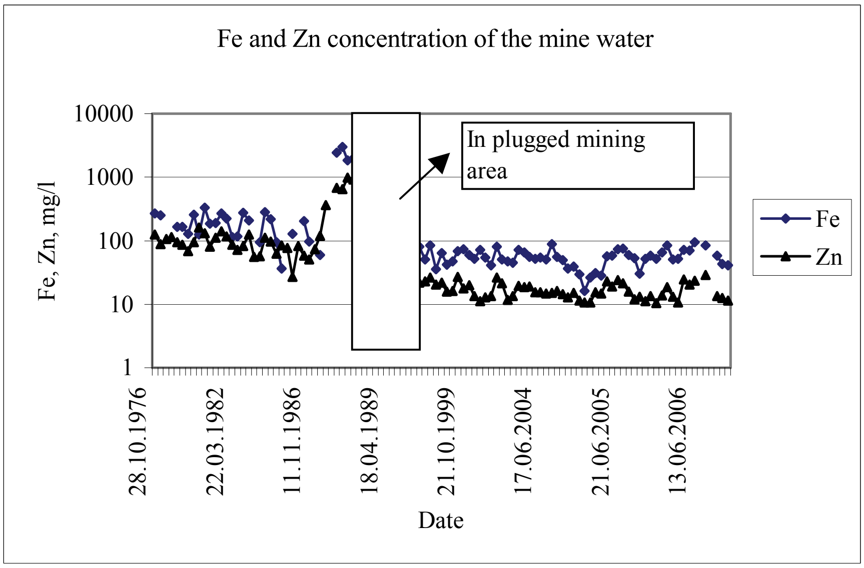

Figure 4. Zinc and iron concentrations in mine water. Very steep increasing of the concentration of components was observed in the plugged mine field during rebound.

It can be seen that the termination of the mining led to remarkable increasing of the pH in mine water from pH~3 to pH~6.2, and decreasing of the TDS from 2.3 g/L to 1.6 g/L. The concentrations of Zn and Fe have been slightly dropping, too. The acidity of the water decreased from 630 to 300 mg $CaCO_3$/L.
Mine water composition in 2006 is presented in Table 2. Previous data collected in 1985 are also given for comparison. Data for the three main mining fields are also presented, but these data are only estimated values. This estimation was carried out because at that time the three mining fields were not accessible, so direct water sampling from the fields was impossible. Nevertheless, for some reasons (e.g. remediation of mining site) it was necessary to give some estimation regarding the composition of the three mine water streams. The estimation was conducted taking into account the former data (relative to the active mining period), geochemical

considerations (e.g. water from flooded field must be much less contaminated than that from aerated zones) and relevant publications (Younger, 2000). According to estimations, the mine water in the field “Mátraszentimre” (which is located above water collecting adit, and where the rock is highly pyritic) was the most contaminated and the most part of the contamination in the resulting mine water derived from the “Mátraszentimre” field. Volume ratio of this water to the total mine water volume was 22%.

Table 2. Concentrations of some selected components in mine water of different origin.

Type of water	pH	TDS mg/L	Acidity* mg/L	SO_4 mg/L	HCO_3 mg/L	Zn mg/L	Fe mg/L	Mn mg/L	As mg/L	Cd mg/L
Mine water 01.10.1985	2.3	2300	650	1790		58	204	4.6		
Mine water 2006 (January-July)	6.23	1625	200	890	101	17	65	4.4	0.167	0.034
Central field flooded**	~7	1200	150	650	150	4	8	1	<0.10	<0.01
Central field opened**	~7	1300	200	700	150	7	20	3	<0.10	<0.01
Mátraszentimre field**	~5	2200	650	1300		49	190	14	0.50	0.20

* $mgCaCO_3/L$; **estimation

It should be mentioned that in the meantime a drilling from the surface (339 m deep) was carried out in the “Mátraszentimre” field. Analytical results of water in the drillhole fitted very well with the predicted values: only sulfate and manganese concentrations were slightly less than the estimated ones. The pH, the zinc, cadmium, arsenic and iron concentrations were practically equal to the predicted values. This means that the chosen approach proved to be acceptable.

Reconstruction of mine water treatment station

Though in last years the mine water became less and less contaminated, the concentration of some contaminants is too high and does not allow discharge without treatment. Therefore, the water treatment must be continued.

The first water treatment plant was built up in 1970s. The used process was very simple: mine water went through two sedimentation tanks (for removing course materials from the mine), then lime milk was added in two steps, most part of the lime into the aerators. Then, the neutralized solution (pH ~ 8.5-9.5) was left to settle in two sedimentation ponds. The treated water was discharged and the sludge was pumped to the temporary sludge disposal valley from time to time. Because the sludge was regarded as a hazard waste, the company was obliged by the environmental authority to replace the sludge into hazard waste disposal repository. The replacement is now underway. Figure 5 shows operations carried out to remove the contaminated sludge from the temporary disposal area to the repository.

Figure 5. Transportation of water treatment sludge to the hazard waste repository.

Taking into account the international practice (Murdock et al., 1994) and the experience at the Horden (UK) (Croxford et al., 2004), it was decided to improve the technological process of water treatment. During the reconstruction, some essential parts of the former facility were maintained (i.e. lime milk preparation, neutralization and aeration tanks). But instead of sedimentation ponds, two sedimentation tanks were built together with one centrifuge for dewatering. Also, polyelectrolyte was used to facilitate the sedimentation process.

The new reconstructed mine water treatment station (planned capacity is 4800 m^3/d) has been working well since March 2006, though the solid content in the centrifuged sludge has to be further increased (at present it is about 40%). In Table 3 some data on the composition of the sludge and treated water are presented. Unfortunately, the sludge is regarded as a hazard waste, especially for its arsenic content (>0.1%). However, the treated water fits very well the established discharge limits. The construction of the new sedimentation tanks is illustrated in Figure 6.

Table 3. Composition of the sludge and quality of the treated water.

	pH	Zn	Fe	Mn	Cd	As	Ca	SO_4	Solid
Sludge from centrifuge, (% in dried material)		5.4	25	0.68	0.010	0.11	~30	~3	
Original mine water, mg/L	6.20	16.2	54.8	5.17	0.03	0.10	215	884	56
Treated mine water, mg/L	8.20	0.27	<0.002	2.6	0.003	<0.01	305	985	5.7
Discharge limit, mg/L	6.5-9.0	5	20	5	0.10	0.50			

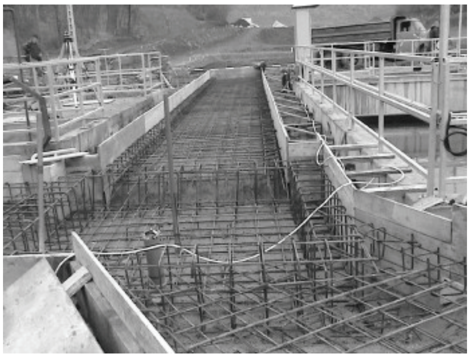

Figure 6. View on the construction of the new sedimentation and dewatering unit.

Conclusions

Termination of mining operations 20 yeas ago led to some improvement of the mine water quality, but it has still to be treated. The reconstruction of the water treatment plant has been completed; the system has been improved by adding two sedimentation tanks and one centrifuge, and by using polyelectrolyte for promoting the sedimentation process. The achieved parameters are in compliance with the expectations: the solid content of the sludge raised substantially, and the quality of the treated water has been improved as well.

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