Mine Water: A Source of Geothermal Energy – Examples from the Rhenish Massif

Georg Wieber [a)], Stefan Pohl [b)]

[a)] *Johannes Gutenberg University of Mainz, applied Geology, Becherweg 21, 55099 Mainz, Germany, email: wieber@uni-mainz.de*
[b)] *geo consult POHL, Im Steinreich 6, 56170 Bendorf, Germany, email: geoconsultpohl@email.de*

Abstact
The Rhenish Massif, situated in Germany, was a region for intensive iron ore and non-ferrous metal ore mining. The underground mining went locally down to deeper than 1,000 metres below ground surface. During active mining the seepage water of the deeper workings was characterised by increasing temperatures. Most mines are decomissioned. The deep workings were flooded with millions of cubic meters of groundwater. A small portion of the (warm) water runs off without any use. But the water within the flooded mines of the Rhenish Massif represents a significant and widespread opportunity for extracting low-grade, geothermal energy. Hence it is necessary to register the abandoned mines and to evaluate if a geothermal usage of mine- and groundwater is feasible.

Key words: Flooded mines, mine water, low-grade geothermal energy, Rhenish Massif, Siegerland – Wied - district, Lahn valley, Hunsrück, temperature of mine water

Introduction
The Rhenish Massif is located in Germany and was a region for intensive iron - and other ore mining like sulphides of lead, zinc and copper. The veins of the Siegerland – Wied – district were some of the most important siderite ore deposits in Europe. Also the pits of the Lahn valley and the Hunsrück area belonged to the (most) productive lead and zinc ore mines in Germany. In 1900 there were 162 mines alone in the Siegerland - Wied district. The total number of mines of the whole Rhenish Massif is estimated to be greater than one thousand individual mines.
The underground mining went down to local depths of more than 1,000 metres. The seepage water of the deeper tunnels was heated to >20°C, locally 50°C was measured during active mining. Mining ceased in the second half of the 20th century. The deep working adits were flooded and groundwater increased up to the level of the drainage- / deep tunnels. The volume of the mine water reservoir, which filled the flooded mines, can amount to several millions of cubic meters. Only a few percent of the volume of these reservoirs are exchanged every year by runoff.

Hydrogeology of Flooded Mines
Temperature
The temperature beneath earth surface increases about 3°C/100 m depth (geothermal gradient of the Rhenish Massif). Herbst & Müller (1969) describe water intrusion with temperatures of 48°C at the deep working adits of the “mercur” mine (Rhenish Massif). But there were many other mines which found water with temperatures above 20°C on the deeper floors (Table 1).

Table 1 *Temperature of drain/ground water during active mining (extract, Fenchel et al., 1985)*

mine:	**adit:**	**temperature [°C]**
Eupel (cleft)	540 m - floor	21,6
Eupel	total runoff	24,9
Georg	640 m - floor	21,75
Neue Haardt	975 m - floor	26,2
Pfannenberger Einigkeit	1070 m - floor	23,6
San Fernando	930 m - floor	26,7
Vereinigung	1000 m - floor	31,7
Wingertshardt	700 m - floor	30,6

Hydraulics

The flooded mines of the Rhenish Massif with their tunnels and shafts are hydraulically comparable with a system of communicating pipes, because of the Devonian sedimentary rocks – the ore veins have been hosted by – are usually characterised by low rock permeability. The mine water of the drainage tunnels consists mainly of upwelling groundwater, with contributions of seepage water from the unsaturated zone. They are partly characterized by productive discharge (up to several dekalitre/s) and by temperatures > 20°C.

Hydrochemistry

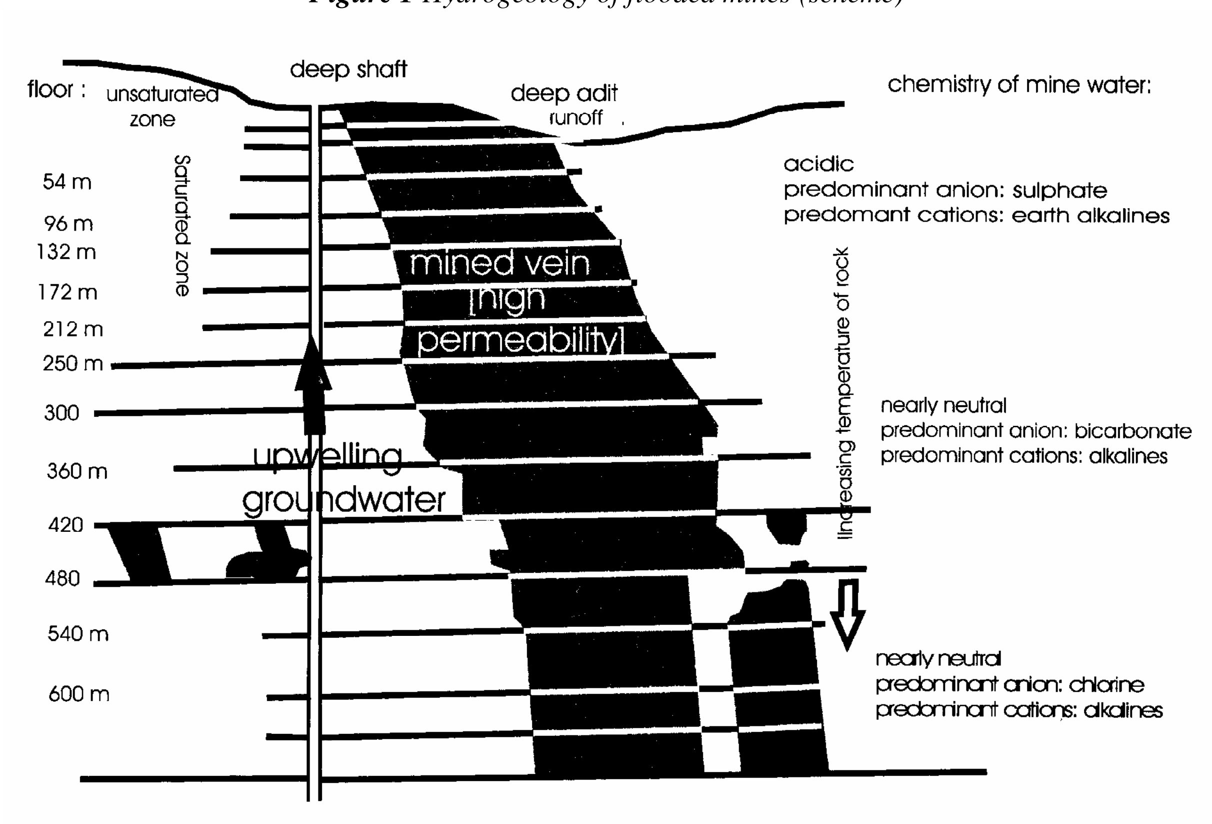
There could have been distinguished three different kinds of groundwater compositions corresponding to depth during active mining (table 2).

Table 2 *Simplified hydrochemical profile of "mine water"*

	predominant anions:	predominant cations:
upper zone:	SO_4	Ca, Mg
middle zone:	HCO_3	Na (Ca, Mg)
deeper zone:	Cl	Na

But after flooding more uniform water quality developed by mixing and transport (convection). The hydrochemical composition will depend on the local/regional geological and hydrogeological situation. But often water of the deep mines (> 800 m) is nearly neutral (pH 6.0 to 8.0), highly mineralized, HCO_3-dominated and the concentrations of iron, manganese and other minor elements have increased.

Figure 1 *Hydrogeology of flooded mines (scheme)*



Geothermal Potential of Flooded Mines

At present we are investigating flooded mines in the Rhenish Massif for utilizing geothermal heat. There are some advantages of flooded mines as compared to natural aquifers:

- excellent heat exchange surface (area) from rock to water caused by mining,
- the geological situation is usually well known and documented,
- great volumes (x 100,000 m³) of impounded mine water (partly > 20°C),
- high permeability and productive discharge of water (dekalitre/s),
- shafts and tunnels for the installation of pumps and heat pump systems exist and are accessible without bigger efforts,
- suitable locations for the installation of pumps and for re-infiltration of cooled water.

The water drainage of abandoned mines has a great geothermal potential for heating many buildings by installing heat pump systems, i.e.:

Table 3 *Water discharge, temperature and geothermal capacity of flooded mines*

Example:	**water discharge:**	**temperature:**	**capacity:**
1) abandoned mine A:	≥ 35 l/s	≥ 24,0 °C	2,800 kW
2) abandoned mine B:	≥ 20 l/s	≥ 15,0 °C	880 kW
3) abandoned mine C:	≥ 10 l/s	≥ 18,0 °C	560 kW
4) abandoned mine D, 2 adits:	ca. 10 l/s	≥ 22,0 °C	720 kW

Very little, only a few percent of the total volume is discharged at the surface each year. The capacities can be optimized by different technical alternatives (i.e. by pumping and/or re-infiltration), but it is necessary performing additional hydrogeological investigations for every individual flooded mine. The heating and cooling capacity of underground mine water is an extremely valuable resource which is currently not being utilized.

Mine Water Use in Geothermal Systems

Germany was a region with intensive mining for hard coal, iron ore and non-ferrous metal ores. Most mines were abandoned, mine pumping shut down and water rebounded to the elevation of the water in deep adits. The runoff and the water reservoirs within the flooded mines are a widespread opportunity for extracting low-grade, geothermal energy. But the exploitation of this regenerating energy is restricted to individual cases (Table 3). A general mapping system for flooded mines does not exist in Germany yet. A formal application is the basis for using this source of energy.

Low enthalpy reservoirs can be tapped by geothermal heat pump technologies. This kind of application is characterised by the fact that the heat source is at lower temperature than the space that is to be heated. Heat can be exploited with the help of a heat exchanger for extracting heat from mine water and a second system with a heat pump. Heat pump systems use refrigerants. These substances undergo liquid-gas phase changes at a wide range of temperatures and pressures. They absorb heat when they vaporize and give up heat when they condense.

Table 4 *Geothermal mine water use in Germany (examples)*

name:	**position:**	**space of time:**	**capacity:**	**use:**
mine Heinrich, hard coal	Essen-Heisingen	since 1984	ca.350 kW	heating of an old peoples' home
mine Zollverein, hard coal	Essen-Katernberg	since ca. 2000		heating of a school of design
shaft 302,	Marienberg/Sachsen	since 2007		adventure-bath
abandoned mine, tin mine	Ehrenfriedersdorf, Sachsen	since ca. 1994		heating of a school
abandoned mine, tin mine	Ehrenfriedersdorf, Sachsen	since ca. 1997	82 kW	museum building, visitor mine

Discussion and Conclusions

There is a great potential for using low grade geothermal energy from abandoned mines of the Rhenish Massif (table 3). But exploitation is limited to realize economic constraints. Important conditions are:

- distance of the mine/adit to potential user,
- discharge of mine water,
- temperature of mine water,
- hydrochemical composition of water,
- mineralisation of mine water,
- stability of the tunnels and adits,
- infrastructure of the workings,
- extent of the mine field,
- depth of the shafts and workings,
- ……

Due to the fact that energy costs for conventional heating (and cooling) are soaring worldwide the economic advantages for using geothermal energy become more and more attractive. The energy output-input ratio is approximately 4 and higher.

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