Stream Thermometry as an Effective Tool for Revealing Communication Areas between Mine Water and Surface Streams: Uranium Mine Rozna Case Study (Czech Republic)

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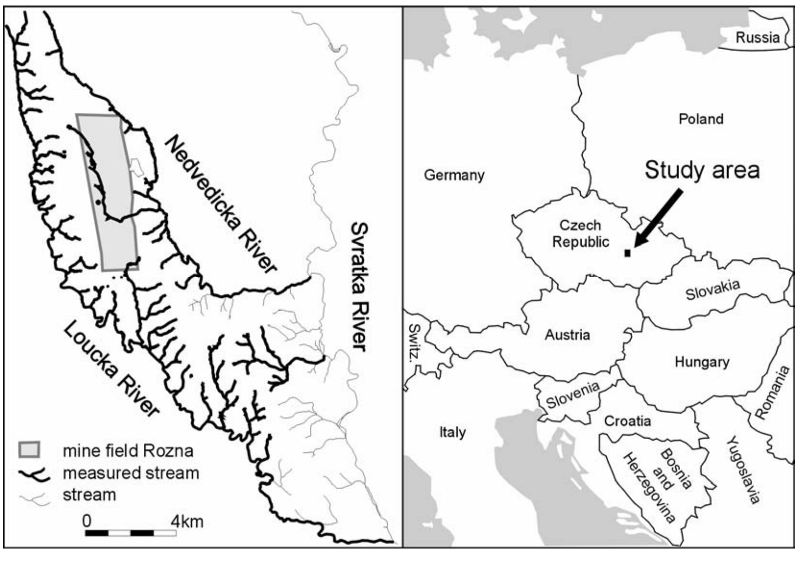
Abstract
The Rozna mine is the last active uranium mine in Europe. When the mine is closed and flooded the original groundwater circulation will be restored. The goal of thermometry was to identify the ground water effluent positions at possible preferential drainage areas and to characterize potentially endangered parts of the mining district and its surroundings. Measured values show that the aquifer is strongly non-homogenous. The majority of groundwater inflows to streams were identified in the environment of amphibolite and brittle rocks such as migmatite, orthogneiss and granite and in the vicinity of structural features, particularly Diagonal – faults in the direction of 55-70°.

Key words: Thermometry, Rock type, Fault system, Uranium mine, Rozna, Czech Republic

Introduction
The subject of investigation is the last active uranium mine in Europe at Rozna, in the Czech Republic (Fig 1). When the mine is eventually closed and, as a consequence flooded, the geochemical conditions will be changed. Without the access of atmospheric oxygen to the mine, the environment will become reducing and reductive dissolution of originally formed supergene minerals will start. The mine water will be contaminated for a few tens of years and the streams draining the mine district of Rozna would be endangered. In addition, the River Svratka, draining the whole area, is the source of drinking water for Brno, the second largest town in the Czech Republic.
The re-established groundwater system will be, in general, associated with an increase of groundwater discharge rates to gaining rivers and streams. Since the groundwater inflows to streams can be contaminated by the mine water, the ground water drainage characteristic of the fractured rock aquifer should be carefully identified in advance. The goal of the investigation described in this paper was to identify the ground water effluent positions at possible preferential drainage areas and to characterize potentially endangered parts of the mining district and its surroundings.

Figure 1 *Study area bounded by Svratka River, Loucka River and Nedvedicka River. Measured streams are marked by bold lines. The study area is shown in the right part of figure.*



Thermometry has been chosen as a tool for the regional investigation of communication between groundwater and streams. Thermometry is a method based on heat measurement and supported by measurement of electrical conductivity. Heat carried by ground water serves as a tracer for identification of interchange with surface water, recharge and discharge, hydraulic conductivity of streambed sediments, flow through fractures and flow patterns in ground water basins and recently to delineate flows in the hyporheic zone, estimate submarine ground water discharge and depth to the salt-water interface, and in parameter estimation with coupled groundwater and heat-flow models (Anderson 2005).

The Rozna mine district is located in the Northeast Ceskomoravska highland, to the North of the Tisnov city. Its natural limits are Svratka River in the southeast, the Loucka River in the west and the Nedvedicka River in the east (Fig. 1). The highest elevation lies in the North 631 m a.s.l., the lowest part is near confluence of the Svratka and the Loucka Rivers in the South at 254 m a.s.l. The area of interest is formed by two flat crests divided by the Rozsochy syncline.

The regional geology consists mainly of metamorphic rocks of the Northwest Strazek part of the Moldanubien. Within the area are predominantly paragneiss, orthogneiss, migmatite, granulite and amphibolite. Marble, quartzite, pegmatite and aplite are much less common. The nappe structure of the Strazek part of the Moldanubien is caused by Variscan orogenesis.

Groundwater flow is connected with porous and mainly fractured media. The shallow aquifer is composed of a combination of poorly-developed Quartenary sediments and the upper part of weathered bedrock. The deeper aquifer is composed of various hard rocks with only fracture porosity. Hard rocks are disrupted by four tectonic systems of faults: Cataclazite zone in the direction of NNW-SSE, Diagonal fault 55-70^{o}, Diagonal fault 280-290° and Fault system 10-40° (Kribek et al. 1997). Various rock types and fault systems influence groundwater flow by different hydraulic properties.

Methods

Field work was carried out in the unusually cold February of 2006. Temperature and electrical conductivity were measured in the majority of the streams between the Loucka, Nedvedicka and Svratka River (Fig. 1). The measured points were localized by GPS and put in GIS with geological (1:20 000 scale) and topographical maps (1:10 000 scale). In accordance with GIS system, the measured points were assigned to and separated into individual groups by two factors: Rock type and Fault system. Within these factors groundwater effluents were divided into several groups:

Rock type Factor – rock types are divided into 4 groups according to mechanical properties:

Brittle rocks – migmatite, orthogneiss, granulite, quartzite and aplite – probably well developed permeable fracture net

Paragneiss – probably less developed permeable fracture net (Michlicek et al. 1986)

Amphibolite – clays (as a product of weathering) plugs the fracture net

Granulite – probably well developed permeable fracture net

Fault system Factor – faults are divided into 6 groups according the fault system direction:

Cataclazite zone in direction NNW-SSE – cataclazite zone is often plugged by hydrothermal carbonates (Kribek et al. 1997)

Diagonal fault system 55-70° – long, continuous fractures without impermeable plug

Diagonal fault system 280-290° – not-continuous fractures, often plugged by impermeable fill

Fault system 10-40° – fractures are often plugged by hydrothermal carbonates

Fault intersection – intersection of cataclazite zone by diagonal faults solely

Groundwater effluents without fault system in the vicinity

Firstly, groundwater effluents (discharges) were picked up from the measured dataset. Identification of groundwater effluents was based on the temperatures measured along the streams. The highest temperature means effluent of groundwater (one highest temperature means one groundwater effluent). In the next step groundwater effluents were statistically evaluated (divided into various groups included in Rock type and Fault system). For each group of the effluents statistical parameters were calculated and visualized by box-and-whiskers plots (temperature and electrical conductivity). Temperature frequency was evaluated in 9 logs within a range of 1 °C (temperature of identified effluents varies from 0 to 9 °C). The sum of the percentage frequency of effluents with temperature exceeding 4 °C was chosen as a limiting value, allowing differentiation of groups within the evaluated factor.

Results and Discussion

During the thermometry 744 measurements were performed and 237 points of groundwater discharge were identified. The distribution of the identified effluents within studied factors is represented in Table 1.

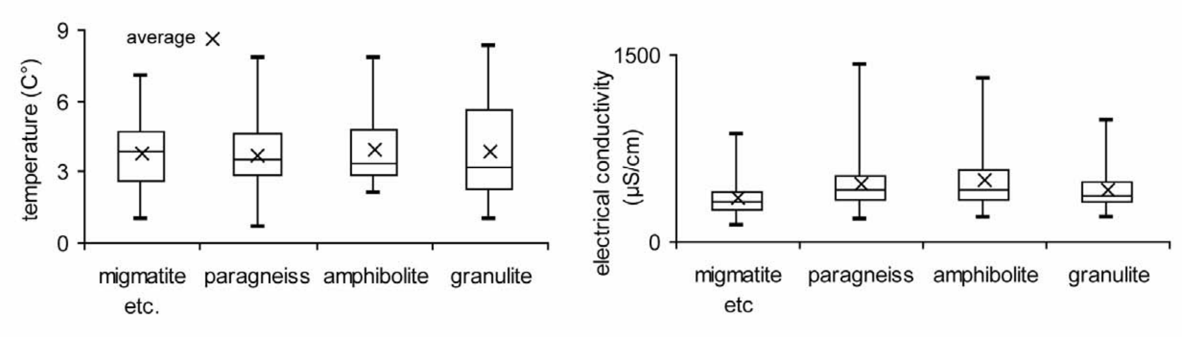
Table 1 *Distribution of the groundwater effluents within the studied factors*

	Evaluated Factor	frequency of the effluents	
		number	%
	Rock type		
Group	migmatite, orthogneiss, granite	79	33.3
Group	paragneiss	88	37.1
Group	amphibolite	25	10.5
Group	granulite	45	19.0
	sum	*237*	*100.0*
	Fault system		
Group	cataclazite zone	58	24.5
Group	diagonal fault 55 - 70°	65	27.4
Group	diagonal fault 280 - 290°	21	8.9
Group	fault system 10 - 40°	4	1.7
Group	fault intersection	23	9.7
Group	without faults	66	27.8
	sum	*237*	*100.0*

The highest frequency of effluents with temperature exceeding 4 °C was found in the group of brittle rocks (49.4% in migmatite, orthogneiss, granite etc.) and in the group of amphibolite (48.0%). These groups have the highest average temperature of the effluent groundwaters (Fig. 2). The highest average temperature is characteristic for the group of amphibolite (4.0 °C). Brittle rocks and amphibolite groups of effluents differ markedly in electrical conductivity. While the brittle rocks group has a very low average electrical conductivity (353.1 µS/cm), the amphibolite group has a significantly higher average electrical conductivity (502.3 µS/cm, Fig. 2). The high temperature of effluents of the brittle rock group and its low electrical conductivity are interpreted as indicating relatively deep and fast groundwater circulation. On the contrary, the high temperature of effluents of the amphibolite group and its high electrical conductivity are interpreted as meaning relatively deep but slow groundwater circulation and/or long flow paths.

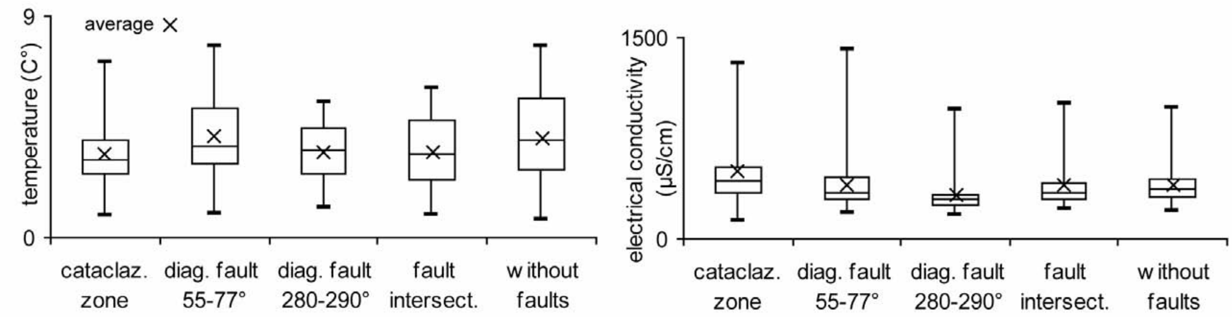
The low median (3.1°C), but high upper quartile (5.5°C) and average temperature (3.8°C) of effluents in the granulite group implies the presence of several hot effluents. The temperature and low average electrical conductivity (413.0 µS/cm) of effluents indicates that the granulite properties allow relatively deep and fast groundwater flow. The lowest frequency of effluents with temperature >4 °C (31.8%), average temperature (3.7°C) and the highest electrical conductivity (461.6 µS/cm) in paragneiss group is interpreted as indicating only shallow and slow groundwater circulation.

Figure 2 *Statistical parameters of the group with effluents distinguished within Rock type factor*



In the same way, as for the Rock type factor, effluents of groundwater were evaluated in the groups of the Fault system factor. The highest frequency with temperature >4 °C have effluents within the Diagonal system group 55-70° (44.6%). This group has also the highest average temperature (4.1°C) and low electrical conductivity (399.1 µS/cm). On the contrary, the lowest frequency of the effluents with temperature >4 °C (31.0 %), average temperature 3.4 °C and the highest electrical conductivity (497.6 μS/cm) has Cataclazite group (Fig. 3). The results indicate that the Diagonal faults in the direction 55-70° drain groundwater and the groundwater flow is relatively fast and deep. The cataclazite zone does not appear to drain groundwater and the groundwater flow near the Cataclazite zone is apparently slow and shallow. Effluents which are not affected by faults can be compared with influent to groundwater flow in both Fault system factor and Rock type factor.

Figure 3 *Statistical parameters of the group with effluents distinguished within Fault system factor*



Conclusion

The temperature and electrical conductivity values show obvious correlation of drainage zones to geological position, as was expected. As for the aquifer drainage characteristic, the aquifer is strongly non-homogenous. The most groundwater inflows to streams were identified in the environment of amphibolite and brittle rocks as migmatite, orthogneiss or granite and in the vicinity of structural diagonal faults in the direction of 55-70°. The thermometry allows identification of places endangered by enhanced potential for formation of contaminated groundwater effluents. Thermometry supported by measurement of electrical conductivity proved that it can be a very useful tool for regional investigation of zones where surface and ground water in fractured rock areas communicate.

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