Hydrogeochemistry of the Mine Water from "Rudna" mine (Lubin Region, South Poland)

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Abstract "Rudna" is one of the mines in Legnica-Głogów Copper Basin (LGOM) – which is the main copper industry center in Poland and one of the world biggest copper extraction sites. "Rudna" is known as a mine with relatively small inflow of groundwater into the dewatering system which ranges from 1.8 to 2.0 m^3/min. TDS of water from Basalkalk ranges from 17.6 g/dm^3 to 328 g/dm^3. Mineralization of Rotliegendes groundwater varies between the minimum value equal to 92.4 g/dm^3 and the maximum one equal to 186.5 g/dm^3. The hydrochemical type of Na-Cl dominates in the mine water samples and Na-Ca-Cl type also occurs sometimes.

Keywords hydrogeochemistry, mine water, copper mine, Rudna mine, Lubin region, Poland

Introduction

"Rudna" is one of the mines in Legnica-Głogów Copper Basin (LGOM) – the main copper industry center in Poland and one of world biggest copper extraction sites. It is located in southwest part of Poland in Lower Silesia Province, about 100 km north–west from Wrocław (fig. 1).

Mining activity in "Rudna" copper mine has been carried out since 1970. The deposits occur at the depth from 690 m in south part of the mine to 1090 m in its north part. Groundwater inflowing to the mine workings located in a deeper part of ground is generally highly mineralized with TDS ranging from 17.6 – 328.8 g/L. Chemistry of mine water is an important factor of the environmental impact induced by mining activity. Mine water from all mines in LGOM area (Rudna, Polkowice-Sieroszowice and Lubin) is mixed and used in the copper ore treatment process. Water excess is drained to the Odra river, near Głogów and is responsible for soluble constituent load to surface water environment. Hydrogeochemistry of mine water in "Rudna" mine is also an important factor for determination of the origin of particular inflows and also for identification of processes responsible for the formation of the specific water type.

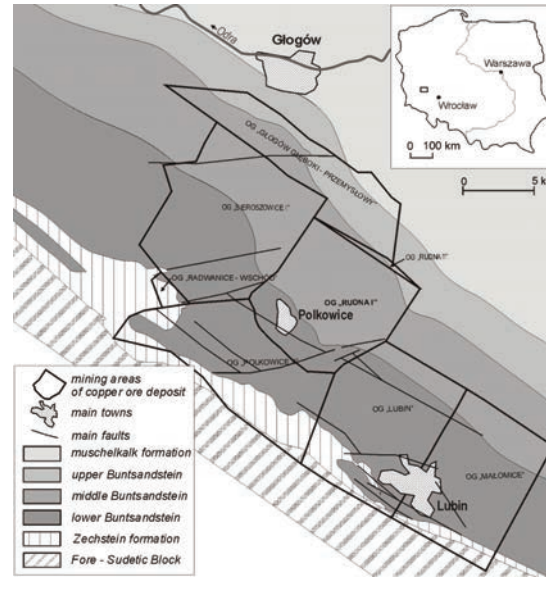

Fig. 1 *Map of the copper deposit occurrence in the Legnica-Głogów Copper Basin (LGOM)*

Geology and Hydrogeology

Copper deposit extracted in "Rudna" mine occurs in Permian limestones and Zechstein dolomites as well as in Rotliegendes sandstones (fig. 1). Permian formation with covering Triassic rocks occurs within the Foresudetic Monocline, dipping north-west at small angle, from 3 to 6°(Bochenska *et al.* 2003; fig. 2).

"Rudna" mine has a relatively low inflow of groundwater water into the mine workings ranging from 1.8 to 2.0 m^3/min. This inflow comes from two aquifers occurring within the Permian formation *i.e.* from carbonate rocks of Basalkalk and sandstones of Rotliegendes. The carbonate Basalkalk aquifer is connected with the Permian dolomite and limestone of average thickness about 52.7 m (7–106 m), with relatively low conductivity range from $1\times10^{-9} - 1\times10^{-6}$ m/s (geometric mean 1×10^{-7} m/s). The Rotliegendes aquifer is built of Permian sandstones with summary thickness of about 300 m. Conductivity of this formation is very low from $1\times10^{-9} - 1\times10^{-6}$ m/s (geometric mean 1×10^{-8} m/s; Worsa-Kozak and Stochel 2013).

During the "Rudna" mine history the main source of water inflows was the Basalkalk aquifer. Since 2003 the inflow from Rotliegendes has increased to 1 m^3/min and thus, it is equal to the value of inflows from the Basalkalk recorded since the beginning of the copper deposit exploitation (fig. 3).

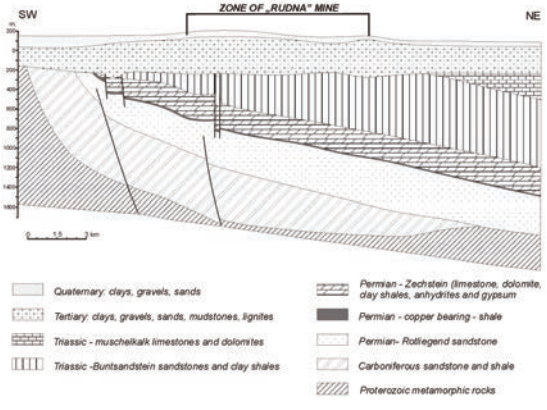

Fig. 2 *Geological cross-section of the "Rudna" mine*

Mine Water Chemistry

Most of groundwater both from the Basalkalk and the Rotliegendes formations are brines. Average mineralization of water from the Basalkalk is about 126 g/dm^3, ranging from 17.6 – 328 g/dm^3. The average mineralization of the Rotliegendes water is 147 g/dm^3 with the minimum value 92.4 g/dm^3 and the maximum one equal to 186.5 g/dm^3 (Worsa-Kozak and Stochel 2013).

Descriptive statistics of the all measured constituents has indicated similarity of the groundwater samples from both Permian aquifer. Average and median values of all parameters have practically the same values with only small difference. Due to the highest amount of analysis of groundwater from the Basalkalk aquifer the observed range of particular constituents of the data is wider then for Rotliegendes (Table 1).

The main fraction in total dissolved solid is forming by concentration of chlorides (Cl) and sodium (Na) ions which is connected with dominance of Na-Cl type groundwater. Average concentrations of other main ions *e.g.* sulfate (SO_4), calcium (Ca) and magnesium (Mg) are much more lesser, only about 1–5 g/L. Especially calcium is observed with concentration values between 0.2–9.4 g/L, and in a few cases forming the groundwater with Na-Ca-Cl type.

Increase of the depth of the mining exploitation in the "Rudna" mine is also connected with the increase of the groundwater sample mineralization (TDS) in both Muschelkal and Rotliegendes aquifers. Chloride concentration in groundwater sample on the co-ordinate about -700 m a.s.l reached the value of about 50–60 g/L. Successive deepening of the "Rudna" mine exploitation level influenced strongly the groundwater TDS. Below the co-ordinate -1000 m a.s.l the groundwater TDS has increased twice to value of about 110–140 g/L (fig. 4). It's obvious that future deepen-

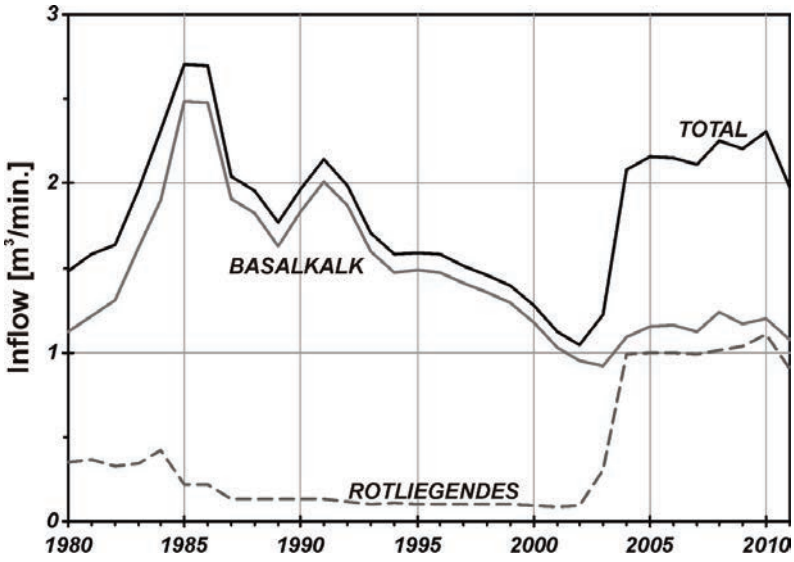

Fig. 3 *Groundwater inflows to the "Rudna" mine from Basalkalk and Rotliegendes aquifers*

ing of the mining workings will be connected with continuation of this evident trend.

Trace elements, connected with the sulfide copper ore, are also occurring in the groundwater inflows to the "Rudna" mine. Unfortunately the significant number of chemical analysis of mine water is without any information concerning concentration of the trace elements. Single analysis of mine water inflows from both Basalkalk and Rotliegendes aquifers have indicated that trace elements concentrations (As, Cr, Cu, Fe, Mn, Pb, Rb, Se, V and Zn) usually range from 0.1 mg/L to a few mg/L. The amount of accessible analysis including trace elements concentration and measurements of mine water pH and redox potential (Eh) is not sufficient to obtain representative characteristics of the concentration range, speciation and mobility. The research project aiming to investigate trace elements occurrence in the mine water from LGOM copper mines is currently at the initial stage. Pre-

Parameter	*Minimum*	*Maximum*	*Average*	*St. dev.*	*25th quantile*	*Median*	*75th quantile*	*n*
				BASALKALK				
pH	3.77	8.01	6.77	0.53	6.42	6.75	7.12	1149
TDS	17600.0	328800.0	125740.1	42435.5	117942.5	132140.0	146047.5	1204
Na	3850.0	119800	40044.1	13331.5	36500.0	40700.0	46650.0	1153
K	10.0	2480.0	509.0	204.1	420.0	520.0	600.0	1153
Ca	268.0	9398.0	4608.3	931.9	4501.4	4711.4	5002.1	1154
Mg	122.4	2138.0	903.4	223.3	838.9	912.8	1001.1	1153
HCO_3	1.2	372.1	142.4	35.5	128.1	140.3	155.6	1177
SO_4	758.0	3481.7	2423.9	255.4	2334.0	2450.1	2535.1	1204
Cl	8376.0	194304.0	69705.3	24527.7	65479.9	72284.4	82000.0	1207
NH_4	0.0	320.0	3.1	9.8	2.1	2.7	3.4	1105
Fe^{2+}	0.0	98.3	1.9	6.1	0.2	0.4	1.1	1117
				ROTLIEGENDES				
pH	5.23	7.30	6.38	0.46	6.12	6.31	6.60	44
TDS	92400.0	186480.0	147073.0	23230.0	132765.0	148260.0	163151.0	44
Na	22600.0	52600.0	46832.7	7358.8	44540.0	47800.0	50250.0	43
K	225.0	855.0	477.4	170.8	332.5	440.0	602.5	43
Ca	3716.4	6572.0	4791.1	641.1	4314.6	4738.2	5252.9	44
Mg	554.5	2497.6	1001.4	406.3	817.2	906.7	970.7	44
HCO_3	61.0	189.1	96.8	24.5	82.4	91.5	115.9	43
SO_4	1952.4	3097.2	2544.9	314.5	2305.6	2587.5	2748.1	44
Cl	48030.5	106734.4	81223.0	13551.0	75875.0	83416.0	89208.4	46
NH_4	0.5	10.95	3.1	1.9	2.0	2.7	4.0	39
Fe^{2+}	0.03	168.0	7.5	25.8	0.2	1.1	3.3	45

Table 1 *Descriptive statistics of mine water chemistry for the Permian aquifers in the "Rudna" mine (concentrations of chemical constituents in mg/L); n: number of samples*

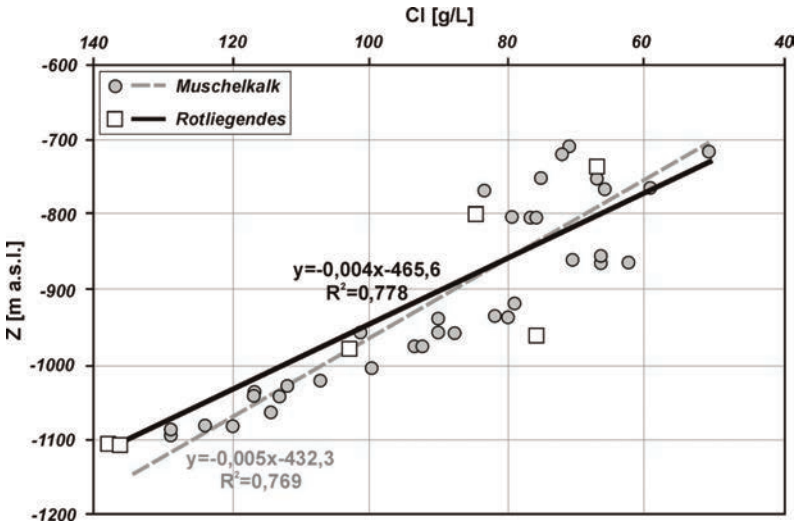

Fig. 4 *Chlorides increasing trend with depth of mining exploitation for both Permian aquifers*

liminary results of this research indicate that in the water inflows to the mine workings both aerobic and anaerobic conditions occurs.

Conclusions

Chemical composition of groundwater in the Basalkalk and the Rotliegendes aquifers is formed mainly by the processes of halite (NaCl) and anhydrite ($CaSO_4$) dissolving. The salts occur in great amounts in the profile of Permian evaporates formation of Zechstein, and their dissolving decides the level of chloride (Cl) and sulfate(SO_4) ions content found in the mine waters. Additionally the process of ion exchange is of basic importance in regard to the concentration of main cations (Na, K, Ca and Mg) in the water under examination.

Copper ore extraction development towards the north is connected with the evident increase of total dissolved solids in the groundwater inflows into the "Rudna" mine workings. It is reason for both much bigger depth of rocks being drained, due to dip of monocline orientation of Permian formation, and with the larger distance from the outcrop zone. The outcrop zone of the Permian formation is covered by a rock mantle and it is the supply area for the Permian (Basalkalk and Rotliegendes) aquifers. In the past, the water inflowing there had the lowest mineralization of all water samples being tested. In connection with the increasing distance from the Permian formation outcrops, the brines with relatively very high mineralization are observed now. With the deeper and deeper extraction, also in the neighboring area of "Głogów-Głęboki Przemysłowy", the further increase of mine waters mineralization, towards the fully saturated brines, is predicted.

Acknowledgements

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