Impact of Zn-Pb ore mining on groundwater quality in the Olkusz region

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Abstract: Long lasting intensive mining drainage has caused profound transformation of hydrodynamic conditions in the Triassic carbonate aquifer and has led to significant groundwater contamination. Two major sources of pollution have been noticed: various sources situated on the ground surface (industrial and municipal landfills, tailings dams, fluid wastes from the paper factory, agriculture) and inner factors (geochemical processes in the extended unsaturated zone). Overlapping impact of these negative factors has caused increase of concentrations of such pollution indicators as: SO4 (up to 11 200 mg/l), Cl (up to 600 mg/l), K (up to 360 mg/l), B (up to 6 mg/l), lignosulfonates (33 mg/l) and NO3 (locally up to 100 mg/l).

1 INTRODUCTION

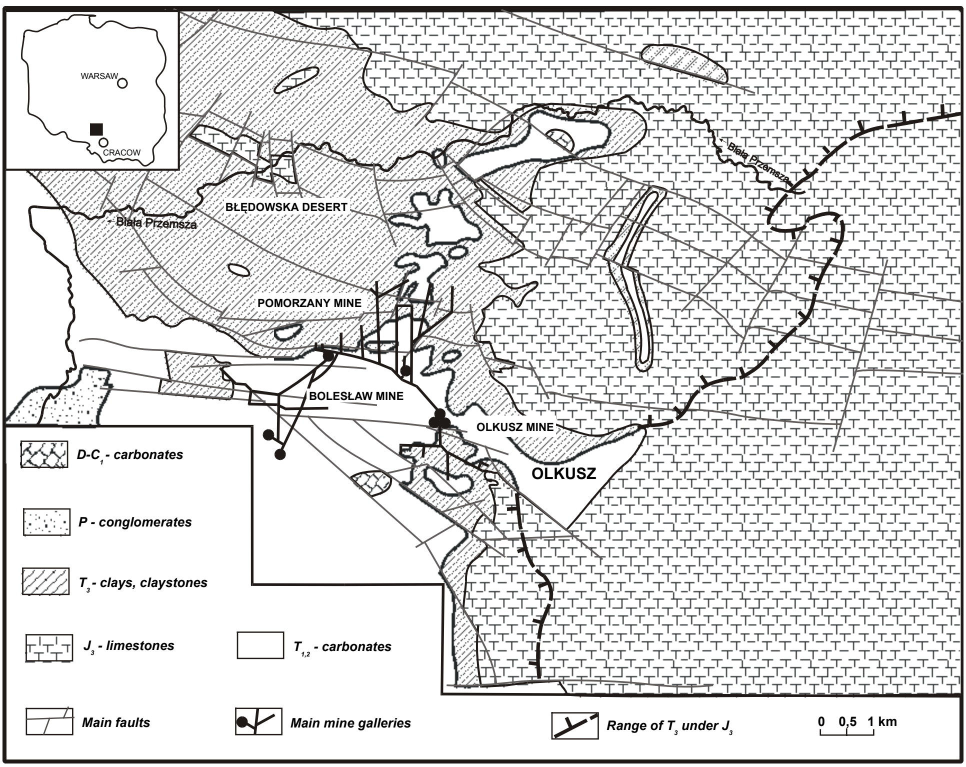
The Olkusz region is the most important area of Zn-Pb ore mining in Poland. Zinc and lead ores occur in dolomites and limestones of the Middle Triassic. There are situated three Zn-Pb ores mines: "Bolesław", "Olkusz" and "Pomorzany". The "Bolesław" mine, the oldest one (existing from the beginning of the XIX century) was abandoned at the end of 1996. The "Olkusz" has existed from 1957 and gradually has been closed down from 1999. The "Pomorzany" mine, the newest and the biggest mine in this region has started its exploitation in 1975. Mining activity in this region has been connected with intensive drainage of the Triassic aquifer. The human impact degree is high in the investigated area. Apart from mines there are localised here processing plants and waste disposals accompanying them. Mining exploitation, high degree of industrialisation and urbanisation have effected in generally high degradation of natural environment in this area. Groundwater quality has been menaced in the substantial range in the Triassic aquifer, being the most important source of potable water in considered area. Direct and indirect impact of Zn-Pb ore mining on groundwater quality of the Triassic aquifer in the Olkusz region has been presented in this paper.

2 HYDROGEOLOGICAL SETTING

The Olkusz region belongs to the Silesian-Cracow Monocline built up of the Triassic and Jurassic formations discordantly overlying folded and faulted

Paleozoic basement. There are Quaternary, Jurassic, Triassic and Paleozoic aquifers in the hydrogeological profile of the Olkusz area (Figure 1). The most important and resourceful is the Triassic carbonate aquifer. Hydraulic structure of fractured and karstified Triassic rocks consists of three types of spaces: pores, fractures and caverns. Limestones represent the fractured-cavernous type of the aquifer while dolomites represent the porous-fractured-cavernous type (Motyka, 1998). Fractures and karstic channels are favourable pathways of groundwater flow while the pore space is the main water reservoir. Unfortunately, because of occurrence of zinc and lead ores in the Triassic dolomites and limestones this aquifer has been subjected to the intensive mining drainage (about 5.5 m^3/s). Intensive mining drainage has caused significant lowering of groundwater table, between 80 and 150 m.

Figure 1 Schematic geological map of Olkusz mining area



Hydraulic properties of these rocks and the form of recharge have the major impact on quantity and quality of water inflowing into the mining excavations. Since Triassic carbonate rocks show porous-fractured-karstic character, their hydraulic conductivity is very changeable (Motyka & Wilk, 1976).

While the average values of coefficient of permeability are 6.5 x 10-5 m/s, its minimal value equals 1.6 x 10-7 m/s, and the maximal – 4.7 x 10-3 m/s. The Triassic aquifer is recharged directly in outcrops areas or indirectly through permeable Quaternary and Jurassic sediments. Important, from the point of view of amount and quality of water recharged the Triassic aquifer are hydraulic contacts of the erosive type noticed between considered aquifer and Quaternary sands or Jurassic limestones (Motyka, 1988) (Figure 2).

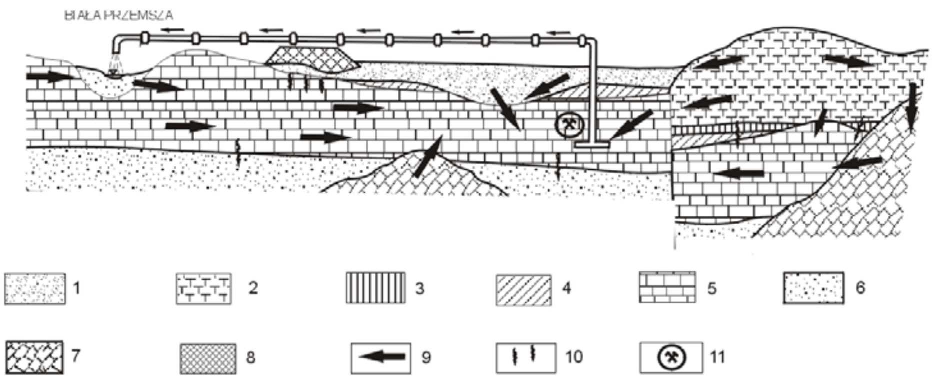


Figure 2 General cross-section
1- Devonian and Lower Carboniferous carbonate rocks, 2- Permian conglomerates, 3- Lower and Middle Triassic carbonate rocks, 4- Keuper clayey sediments, 5- Middle Jurassic marls, 6- Upper Jurassic limestones, 7- Quaternary sands, 8- Direction of intensive groundwater flow, 9- Direction of water leakage, 10- Landfill, 11- Mine (according to Motyka and Wilk, 1980).

Hydraulic contacts of the erosive type, noticed between the considered aquifer and the Quaternary sands or Jurassic limestones, are of the high importance from the point of view of amount and quality of water recharging the Triassic aquifer.

The Triassic aquifer is covered by the isolating clayey Rhaetian-Keuper sediments in the large area (Figure 1).

3 IMPACT OF SOURCES OF POLLUTION SITUATED ON THE GROUND SURFACE

Long lasting intensive drainage has led to profound transformation of hydrodynamic conditions resulted in changes of flow directions, increase of hydraulic gradients, and changes of hydrogeochemical conditions in the considered region. Recently, major groundwater streams are directed to mining excavations. Soon after that, groundwater contaminated by various substances from different pollution sources has begun to flow into ore mines. The most important of the pollution sources are dumps and tailings dams, municipal landfills, liquid wastes from paper factory; agricultural contaminations.

During the process of ore enrichment tailings are formed. Their basic component is pulverised dolomite. In significant amounts marcasite occurs, and as accessory minerals, quartz, calcite, sphalerite, cerussite, anglesite, galena and argillaceous minerals (Adamczyk & Haładus, 1994). Tailings are disposed to their disposals as pulp (semi-liquid rock-watery mixture), from which water, used to their transport leaks, after the disposal. Since tailings dams, situated between the Bolesław and Olkusz mines (Figure 3), were made without any protection against effluents infiltration to the basement, such infiltration occurs. Its range, calculated basing on water balance, is about 5.3 m^3/min.

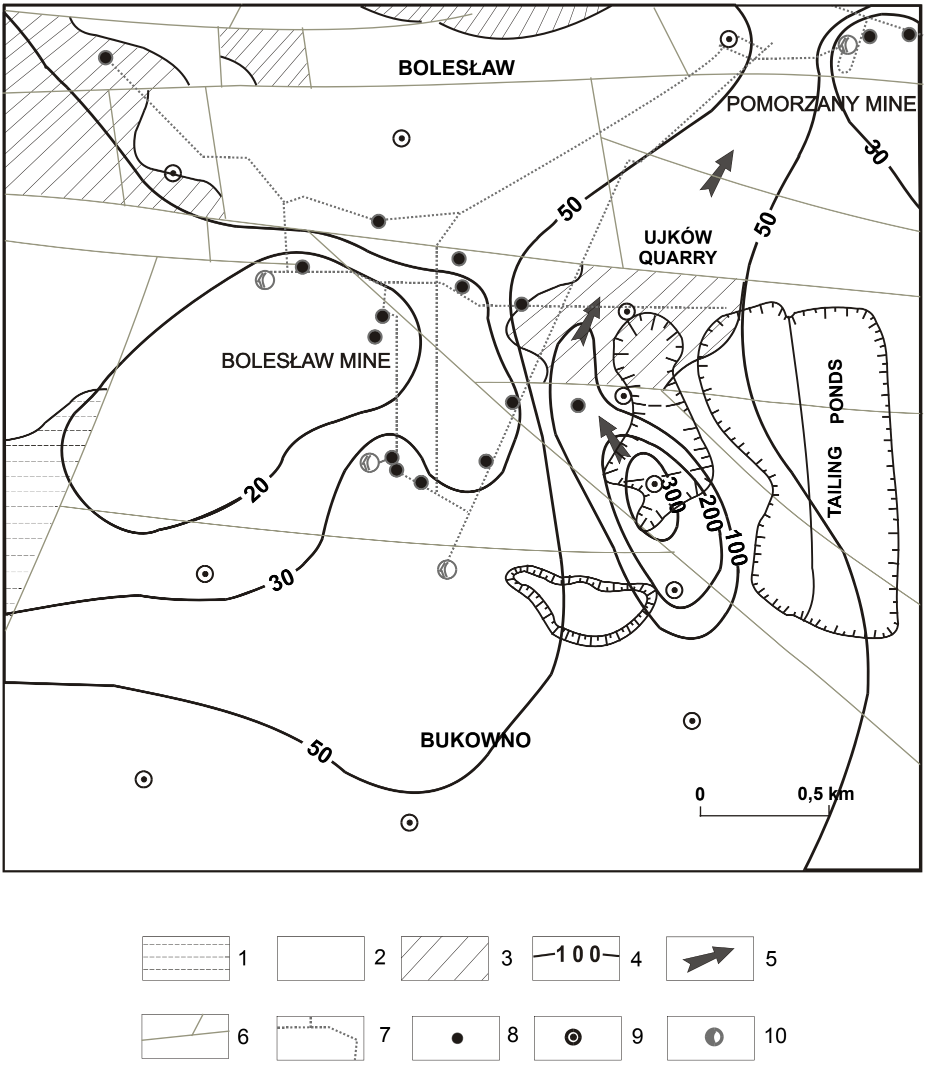


Figure 3 Concentration of Cl^- in groundwater sampled near "Bolesław" Mine (Ujków Quarry)

1- Permian: tills, conglomerates, 2- Rhoetian and Muschelkalk: dolomites and limestones, 3- Keuper: clays, 4- chloride concentration (mg/l), 5- direction of polluted water flow, 6- faults, 7- main galleries, 8- sampled inflows, 9- observation wells, 10- shafts

According to Adamczyk & Haładus (1994), water infiltrating from tailings dams contains from 1100 to 1800 mg/l of sulphates (SO_4), from 0.4 to 47 mg/l of zinc (Zn) and to 7.4 mg/l of lead (Pb). Moreover, increased concentration values of cadmium (Cd), copper (Cu), arsenic (As) and nickel (Ni), components of sulphide minerals, have been found. Water, infiltrating from the tailings dams, inflows mainly to the southern part of the "Pomorzany" mine (about 65%) and to the western part of the "Olkusz" mine (about 30%).

Between the "Bolesław" and "Pomorzany" mines there is situated a disposal of the discards from the rolldown furnaces (Figure 2). As it has been shown by approximate estimation there is about 3 million tons of discards in this dump, composed mainly of calcite (15-35 %), magnetite (10-20%) and dolomite (5-15%). Apart them, sphalerite, quartz, zincite, brucite, and iron hydroxides occur as accessory minerals (Adamczyk & Haładus, 1994).

In the eighties and nineties, acid wastes from the sulfuric acid plant were disposed in this disposal due to good buffering properties of discards from rolldown furnaces. On the average, about 2-3 m^3/min of wastes were dumped here, with pH of about 3 and sulphate content 2 500 mg/l. The buffering process in the environment of dolomites, occurring in the dump basement, has caused the increase of sulphate and heavy metal concentrations in groundwater. Piezometric measurements, taken in nearby of the described dump, has shown that there are 3000-4000 mg/l of SO4 ion, 5-14 mg/l of Zn, 2-3 mg/l of Mn, 0.7-10 mg/l of Fe, up to 0,05 mg/l of As and 0.02-0.03 mg/l of Ni. Infiltration of neutralised acid wastes has caused the increase of sulphate content, primarily in cumulative water of the "Bolesław" mine, of about 900 mg/l.

Municipal wastes has been disposed in the abandoned "Ujków" quarry, located to the east of the "Bolesław" mine, where galmei was exploited. The southern part of the quarry has been infilled by these wastes without any protection against effluent infiltration from this landfill to the basement built of fractured and karstic ore-bearing dolomites. So, highly polluted wastes filtrate to the basement despite of the landfill reclamation. Main components of effluents are chlorides, which concentration reach 2000 mg/l, bicarbonates - 6000 mg/l, periodically sulphates - 750 mg/l, sodium - 1200 mg/l, potassium - 1100 mg/l, magnesium - 950 mg/l and ammonium ion more than 500 mg/l. Among microelements, the following of them occur in the highest amounts: boron, which concentration reaches of about 5 mg/l, aluminium up to 1.8 mg/l, manganese – 1.3 m/l and lead up to 0.17 mg/l.

As a result of effluent infiltrating from the municipal waste disposal to the Triassic basement, the increased values of chloride concentration have been found in groundwater from its surroundings, reaching in the nearest monitoring point up to 600 mg/l, in the case of sodium concentration - up to 460 mg/l, potassium - up to 360 mg/l and boron - up to 6 mg/l. Due to oxidation of ammonium ion with simultaneous nitrogen consumption by bacteria in groundwater increased nitrate concentration has been found, locally reaching up to 100 mg/l.

The front of groundwater, polluted by effluents from the municipal waste disposal, moves in direction of the workings of the southern part of the "Pomorzany" mine. It is illustrated by a map of chloride ion concentration in groundwater from the surroundings of the Ujków quarry (Figure 3).

In the period of 1930-1979 a paper factory in Klucze deposited about 450 000 tons of lignosulfonates lyes to the Quaternary sands. The pollutant migrated through the unsaturated zone to the water table and sank in the aquifer, filling in the paleo-river depression at the bottom. The polluted area was about 2 km^2, and the thickness of the polluted waterbody was about 25 m. The highest pollutant concentration found at the bottom was 33 mg/l, and it was regularly decreasing to 1 mg/l (Motyka et al.,1994).

As a result of deep mining drainage, lignosulfonates deposited in the Quaternary aquifer have infiltrated the Triassic carbonate rocks and, according to the newly formed system of the hydrodynamic field, have begun to migrate to the "Pomorzany" mine workings.

The transport of this pollutant to the mine probably started in November 1974, when the cone of depression in the Triassic aquifer reached the hydrogeological window close to the disposal site, as known from piezometric observation. The first measurable portions appeared in mining water in September 1977 yr., so 3 years after their migration to the Triassic aquifer (Figure 4).

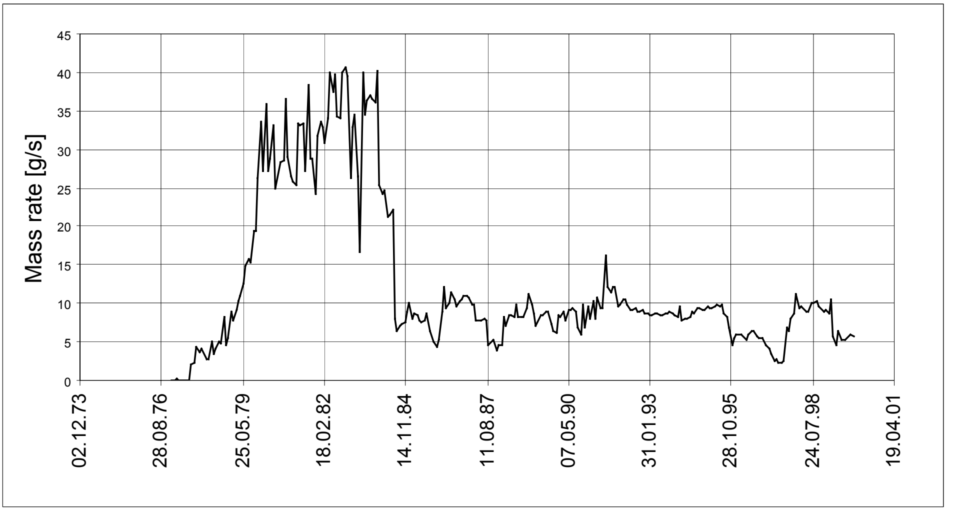


Figure 4 Lignosulfonates breakthrough curve

The maximum of the lignosulfonate mass rate, e.i. from 35 to 40 g/s, was detected in 1980-1983 years. Next the lignosulfonate concentration decreased quickly and their mass rate has stabilised on the 5-10g/s level.

The drop in the concentration in 1984 coincided with a development of a deeper mine level, which overtook a large portion of flow. However, neither the total inflow to the mine decreased nor the shape of the cone of depression had changed. Therefore, that large change must be attributed to the decrease of inflow from the Quaternary sediments caused by a sudden drop of water table close to the hydrogeological window. After that large change, the concentration of lignosulfonates remained constant next years (Figure 4).

About 60% of groundwater of good quality, inflowing to the "Pomorzany" mine, has been polluted by lignosulfonates. Due to presence of this pollutant that groundwater does not meet drinking water quality standards and is treated as wastes. Its draining to the Biała Przemsza river raises additionally the cost of the Zn-Pb ore exploitation.

As a result of bad water-waste management in the area of the Jurassic carbonate aquifer occurrence, particularly in rural settlements, non- purified domestic sewage and agricultural contaminants easy infiltrate to this aquifer, which is not protected by overlying sediments. The process of groundwater quality degradation can be seen due to fractured-karstic character of the Jurassic limestones and connected with that low capabilities of groundwater self-purification. It shows mainly by the increase of nitrate concentration which the average value exceeds 50 mg/l, maximally reaching more than 100 mg/l in some monitoring points (wells).

Through the complex, direct and indirect zones of hydraulic connections of the Jurassic and Triassic aquifers nitrogen compounds permeate to the Triassic carbonate formation and in the area of the depression cone migrate in the direction of the mining workings. In some inflows in the "Olkusz"and "Pomorzany" mines the nitrate presence has been already discovered, with maximal concentration exceeding 20 mg/l.

4 IMPACT OF INNER FACTORS

In the Olkusz region deep mining drainage has caused formation of a new extensive unsaturated zone. Dewatered, ore-bearing Triassic rocks, originally occurring under suboxic conditions, are now within oxic condition zone. Oxidation of sulphide mineral takes place in this situation. Weathering of iron sulphides, i.e. pyrite and marcasite, is particularly disadvantageous since their oxidation reactions cause significant decrease of pH values of solutions, meaning the increase of groundwater acidity (Singer & Stumm, 1970). Metal mobility increases in acid environment, i.e. their concentrations in water environment. In the carbonate rocks hosting sulphides in the Olkusz region, due to buffering process rapid neutralisation of acid solution occurs and change of the pH values into alkaline reaction.

The result of the buffering reaction is the increase of groundwater hardness and sulphate content (Smith et al., 1994). Particularly high concentration of sulphates is generated when buffering reactions occur in the dolomite environment because well soluble magnesium sulphates are formed as reaction products (Fernandez-Rubio et al., 1986). Buffering process causes precipitation of salts of metals from an aqueous solution. Despite the removal of metals from an aqueous solution, concentrations of some of them remain generally higher than in natural solutions.

Groundwater of the shallow zone of circulation in limestones and dolomites is usually of good quality, even when deposits of sulphide ores appear there. Before intensive mining activity TDS of groundwater in the Triassic carbonate rocks in the Olkusz region varied between 250 and 500 mg/dm^3 and average concentra-tions of sulphates were 37 mg/dm^3, zinc – 0.52 mg/dm^3, lead – 0.06 mg/dm^3 (Adamczyk & Wilk, 1976).

As a result of overlapping effects of weathering of sulphides and impact of the contamination sources described above, the groundwater quality of the Triassic aquifers has decreased in the large area of its occurrence (Motyka & Witkowski, 1999). The example is distribution of sulphate concentration in the samples of groundwater from the Triassic limestones and dolomites, taken from water inflows into the "Bolesław", "Olkusz" and "Pomorzany" as well as from observation wells, wells and springs (Figure 5).

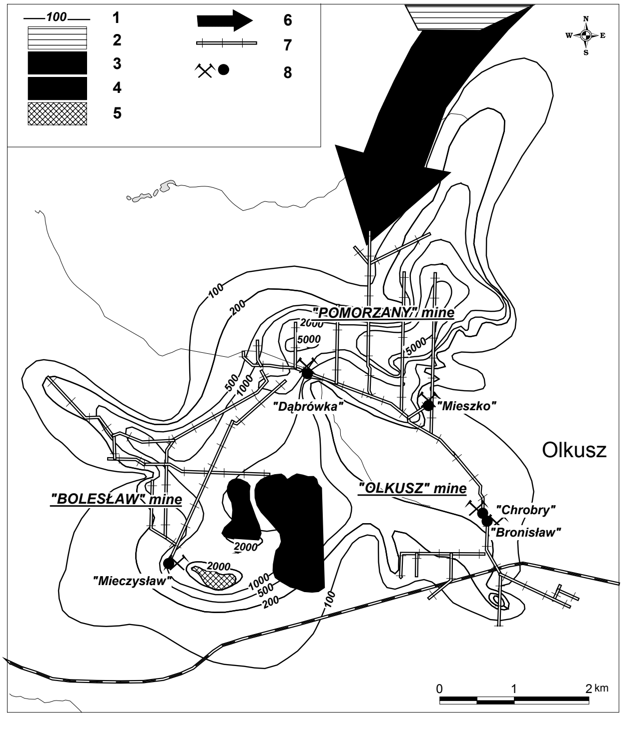


Figure 5 Concentration of sulphates in groundwater of the Triassic carbonate aquifer

1- Contour of sulphates concentration in groundwater (mg/l), Waste disposal: 2- area of injection of lignosulfonates, 3- tailing dam, 4- municipal solid wastes, 5- industrial wastes, 6- Flow direction of groundwater polluted by lignosulfonates, 7- Zn-Pb ore mines workings, 8- shafts

It is clearly seen that high sulphate concentrations, E.I. above 200 mg/l (drinking water quality standard in Poland), has been discovered in the central mine parts and near the previously described sources of pollution. The highest sulphate concentration, exceeding 2000 mg/l has been found in water inflows and observation wells situated near the main dislocation in this region (named the Pomorzany fault) and in the regionof erosional windows in the isolating Keuper formation. In the "Pomorzany" mine the sulphate concentration has exceeded 5000 mg/l in a few water inflows, reaching maximal value more than 11200 mg/l.

There are two possible mechanisms of formation of solutions with so high sulphate concentrations. In the "Bolesław" mine, apart from sulphide weathering processes, large impact has resulted from infiltration of groundwater from the surface contamination sources, particularly tailings dams (Adamczyk & Haładus, 1994), as well as dumps of discards from rolldown furnaces and the municipal waste disposal situated in the southern part of the abandoned Ujków quarry.

Groundwaters of high sulphate concentration are formed in the "Pomorzany" mine due to washing of the young unsaturated zone, rich in weathering products (sulphate minerals), by groundwater infiltrating to the Triassic carbonate formation in the zones of erosional windows in the isolating Keuper formation (Figure 6A), and in the zone of the Pomorzany fault, where probably continuity of the groundwater table has been broken in the downthrown and upthrown sides (Figure 6B). Also in water inflows into the "Olkusz" mine, in the region of the small erosional window, sulphate concentration more than 1000 mg/l has been registered (Figure 5). The mechanism of washing of sulphate minerals from the young unsaturated zone can also be initiated by backfilling waters, migrating from these mine regions where hydraulic backfilling has been applied.

Sulphate concentration in groundwater of the Triassic aquifer in the surroundings of the Olkusz region mines of Zn-Pb ores is only one of indicators of the stage of their degradation. In groundwaters with high sulphate concentrations also increased values of concentration of metals have been registered, usually these of iron, zinc, manganese, nickel, copper, and cadmium. In some water inflows slightly increased concentrations of arsenic, lead and thallium has been found, comparing to their background.

5 SUMMARY

The considered region is subjected to serious risk of groundwater contamination. Location of many sources of pollution (landfills, tailings dams) there, without any protective measures, as well as fluid waste injection into the ground have led to significant contamination of groundwater in the shallow Quaternary aquifer. Negative changes in hydrodynamic conditions caused by intensive long lasting mining drainage have resulted in activation of many natural contacts between aquifers. It has led to contamination of the Triassic aquifer. Additionally, geochemical processes in the extended unsaturated zone have caused increase of contamination of the Triassic aquifer, reflected mainly in very

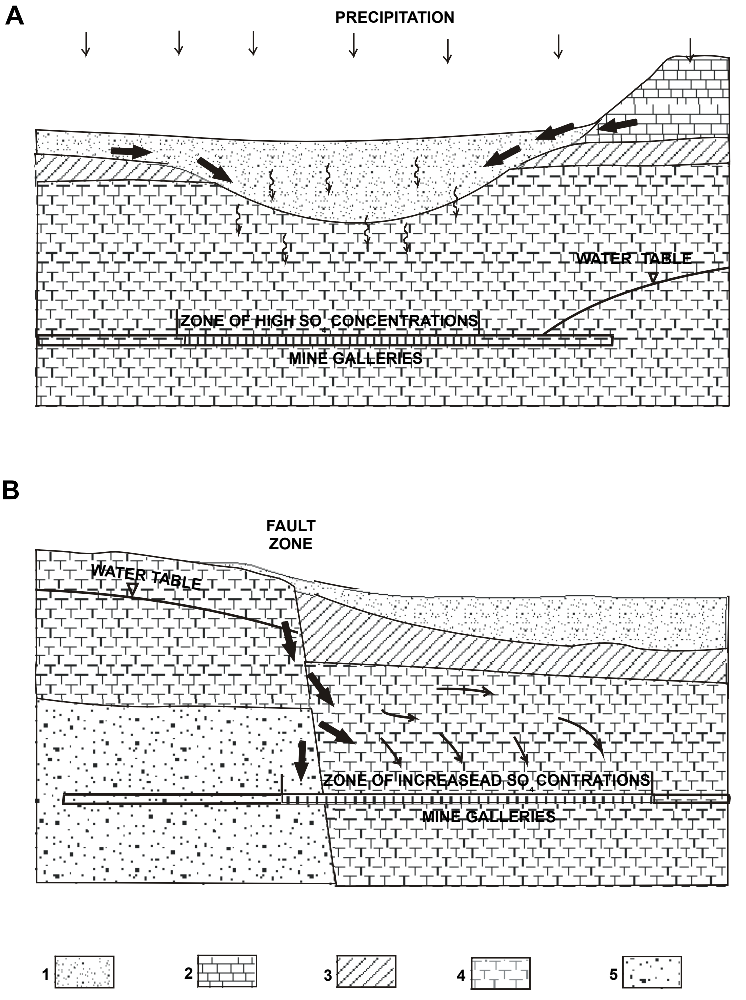


Figure 6 Scheme of formation of increased SO_4 concentrations in Zn-Pb mines
1- Quaternary: sands, 2- Jurassic: limestones, 3- Keuper: clays, 4- Lower and Middle Triassic: carbonates, 5- Permian: conglomerates

high contents of SO_4. Pollution from tailings dams, municipal landfill as well as injected lignosulfonates and great amount of sulphates originated in the extended unsaturated zone have been directed to the biggest still active the “Pomorzany” mine. This situation is particularly warning. At present about

60% of water (about 150 m^3/min) pumped out from the "Pomorzany" mine is polluted. Situation could be even worse after closing of the "Olkusz" mine.

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Wpływ górnictwa rud cynku i ołowiu na jakość wód podziemnych w rejonie olkuskim

Zbigniew Adamczyk, Jacek Motyka, Andrzej Witkowski

Streszczenie: Na tle ogólnych warunków przepływu wód podziemnych w olkuskim rejonie kopalnictwa rud cynku i ołowiu omówiono zmiany jakości wód podziemnych spowodowane działalnością górniczą. Głęboki drenaż wód podziemnych uruchomił przepływ skażonych wód z ognisk zanieczyszczeń na powierzchni terenu, co spowodowało lokalną degradacje jakości wody. Z drugiej strony endogenne procesy wietrzenia minerałów siarczkowych w strefie zdepresjonowanej doprowadziły do degradacji wód podziemnych na dużą skalę.