# Coal mine water chemistry (Upper Silesian Coal Basin, Poland)

Andrzej Różkowski

*University of Silesia, Faculty of Earth Sciences, Będzińska 60, 41-200 Sosnowiec, Poland. e-mail: rozkowsk@us.edu.pl*

**Abstract:** Chemistry of coal mine water in the Upper Silesian Coal Basin (USCB) varies between the various geological structures of the USCB. It depends on geological and mining factors. The influence of mining activity on groundwater chemistry depends on the duration, size, depth and system of coal exploitation. There is a general trend of increasing mine water mineralization with depth. Mine waters are pumped out from 50 coal mines in total quantity of 692 $m^3$/min. TDS of natural mine water ranges from 0.2 to 372 g/l but the cumulative pumped out water mineralization is from a few to 110 g/l. The fresh water and brackish water (above 70% of total amount) dominate among pumped out mine waters.

## 1 INTRODUCTION

The Upper Silesian Coal Basin (USCB) is now one of the biggest coal basins in Europe. Mining has been active here since the second half of the 18th century. Underground mining and intensive activity of associated industries have effected in disturbance of the natural hydrogeological conditions. The main phenomena causing the changes in the hydrogeological environment include the drainage of rock massif, alteration of flow systems and changes of water chemistry. Geological structure, recharge conditions of the Carboniferous water-bearing sandstones and the mining activities influenced the hydrochemical differentiation of the mine water. Chemistry of mine water in the depth interval to 1,200 m have been formed in different geological structures and has transformed groundwater regime due to changeable impact of mining.

## 2 GEOLOGICAL BACKGROUND

The Upper Silesian Coal Basin (USCB), 7500 sq. km in area including 5500 sq. km inside of the Poland borders, is situated within the Upper Silesian Variscean depression. The basement of productive rocks of the USCB consists of Precambrian, Cambrian, Devonian and Lower Carboniferous sequences.

The coal-bearing Upper Carboniferous formation of the USCB includes four lithostratigraphic series, 8500 m in total thickness, developed within the zones of the greatest basinal subsidence. The series belong to the Namurian A, B, C and Westphalian A, B, C and are composed of sandstones, siltstones, claystones and coal seams. They are characterized by a gradual reduction of their thickness toward the east and south-east.

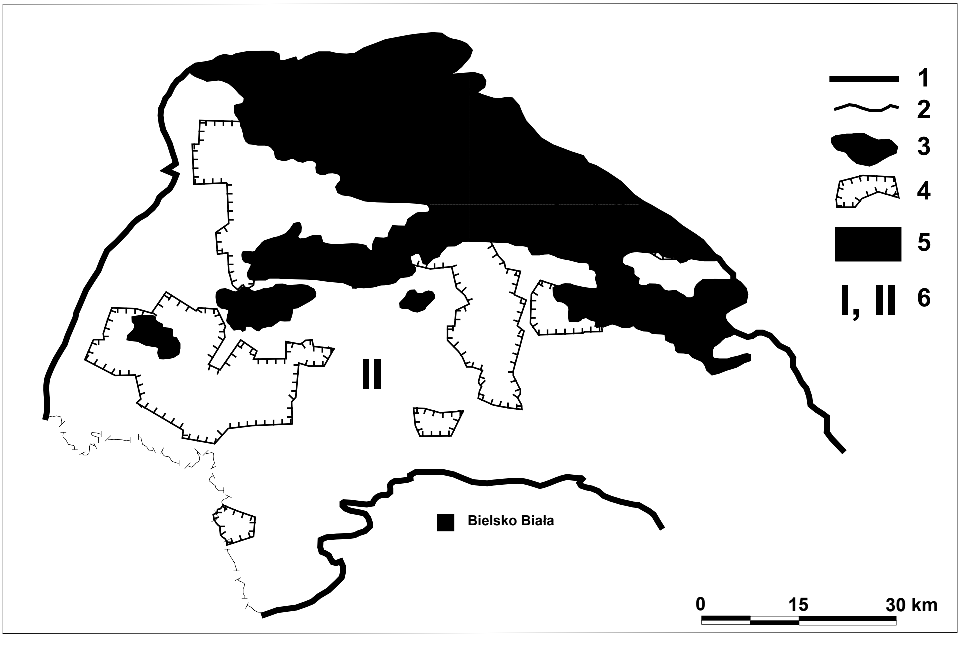


Figure 1 Upper Silesian Coal Basin (USCB)
*1 - extension of the USCB; 2 – extension of the isolating series of the Tertiary formation; 3 – salt deposits in the Tertiary formation; 4 – mine areas; 5 – recharge areas of the Carboniferous aquifers; 6 – hydrogeological region*

The coal-bearing Carboniferous formations of the basin are covered by the Permian, Triassic, Jurassic, Tertiary and Quaternary deposits in the north-eastern part of the USCB. The Permian and Jurassic deposits cover a very small portion of the basin, stretching along the north-east boundary of the Carboniferous subcrops.

The Triassic formations, represented mainly by dolomites and limestones, reach up to 200 m in the thickness. The clayey Tertiary formation covers the Carboniferous complex in the southern and north-western parts of the basin (Figure1). The thickness of that formation reaches up to 1000 m in the southernmost area of the USCB. The Quaternary sediments consist of the glacial deposits as well as sands and gravels of the fluvioglacial accumulation.

Two tectonic zones have been distinguished in the Carboniferous rocks of the USCB: 1/ the zone of fold tectonics, and 2/ the zone of disjunctive tectonics. The dominant part of the basin lies within the zone of disjunctive tectonics. Numerous faults, as well as very flat anticlines, domes, synclinal zones or troughs represent the main structural elements.

## 3 COAL MINING

Poland remains one of the top hard-coal producing countries, in terms of reserves, production and export (Kotas, 1994). Production in the Upper Silesian Coal Basin (USCB) has started early in the 18th century. Recently, the annual production of coal in Polish part of the basin is about 130 million tons.

At present, there are 50 active mines in the Polish part of the USCB. All mining is carried out underground. Due to the great number of mineable coal seams in the sequence, the mining operation are carried out simultaneously at several depth levels, covering almost entire surface of mining area; this hold true particularly for old coal mines. All of the underground mines utilize longwall design for production; the room - and - pillar mining method, primarily developed in Upper Silesia, is not in use any more. The location of coal mine areas in the basin is shown on the Figure 1. The majority of coal mines are disposed in the area of shallow occurence of the productive Carboniferous beds. The oldest mines are situated in the northern part of the basin along the Main Anticline and the Bytom and Dąbrowa troughs. Together with mines located in the northernmost part of the Main Syncline they form the Upper Silesian Industrial Region (GOP). The mines belonging to the Cracow mining area are located in the easternmost part of the basin. The mines situated in the south-western part of the USCB, constitute the Rybnik Coal Basin (ROW), extensively developed during the post-second World War decades.

The coal fields cover the area of about 2000 sq. km. The depth of mining works varies from 300 to 1200 m. It should be stressed that in connection with construction of new deeper exploitation levels in old mines and building of new deeper mines in the area of the Main Syncline, the mean depth of mining works is increasing; e.g. in 1957 yr. the mean depth of mining works was about 300 m while in 1989 yr. - 650 m. There is observed also the increase of groundwater inflow to the mine workings from 494.2 $m^3$/min in 1956 yr. to 692 $m^3$/min. in 1998 yr. In the meantime, mineralization of the cumulative pumped out mine water increased from 4.9 g/l in 1970 to 12.5 g/l in 1993 yr.

Deterioration of coal mining conditions in the USCB is caused by depletion of reserves in the thick coal seams in old mining areas. New coal mines and new exploitation levels in old mines are forced to extract the thin coal seams at considerable depth and to pump out mining water of very high salinity.

According to the Wilk’s classification (1960), the USCB coal mines belong to four groups by the amount of water pumped out: with low, moderate, abundant and very abundant water inflow. The dominant mines are these with low and moderate water inflow, from 1 to 6 $m^3$/min. But the mines of very abundant water inflow, over 18 $m^3$/min, pump out about 53% of the total water inflow though they represent only 15% of all mines. As a rule their mining depth is in the range from 200 m to 500 m and they are situated in the area where the Carboniferous formations are covered with permeable overburden.

There is no observed the distinct dependence of water inflow on general output of mine. The most of mines (58%) with generally high output, over 1.5

million t/y, belong to the low and moderate classes of water inflow. The water production index is in the range from 0.05 to 21.6 $m^3$ per ton of output. But there is observed certain correlation between the amount of mine water pumped out and its exploitation area. The unit inflow is in the range from 0.02 to 2.09 $m^3/min/km^2$.

The deep mines (over 700 m deep) are mostly the mines with low and moderate water inflow.

## 4 HYDROGEOLOGICAL CHARACTERISTICS OF THE USCB

Three water-bearing formations have been identified in the hydrogeological section of the USCB: Quaternary, Mesozoic and Carboniferous ones. The Tertiary clay sediments constitute a separate, isolating formation.

In the NE part of the basin the rocks of the Carboniferous formation crop out or are overlain by permeable Mesozoic, mainly the Triassic carbonates and Quaternary sands. In its southern and western parts the formation is overlain by the impervious Tertiary clays (Figure 1).

The Upper Carboniferous formation is represented by a clay-silt-sandstone complex containing coal seams. The Carboniferous water-bearing sandstones and conglomerates have thickness ranging from 0.5 to several dozen meters. They are isolated one from another by intercalations of impermeable claystones, except fault zones, zones of sedimentary wedging as well as areas of mining.

The structure of the basin is various. The syncline structures constitute the groundwater aquifers with defined flow routes and definite recharge and discharge areas. The anticline structures, in the northern part of the USCB, are treated as the main recharge areas of the Carboniferous hydraulic systems because of their hypsometric position and occurence of permeable overburden there. Within the individual geological structures the various hydrogeological conditions occur because of the different geological structure.

The Carboniferous aquifers are recharged in zones of outcrops or through permeable covering rocks in the north-eastern part of the USCB (Figure 1). Locally recharge takes place also in the central part of the basin, in the areas where Tertiary sediments have been eroded or their thickness is very low. The recharge of the Carboniferous aquifers by Quaternary sands from recent and buried valleys is the most active.

Taking into account the recharge conditions of the Carboniferous water-bearing sandstones two hydrogeological regions (I, II) may be distinguished in the USCB. Their boundaries are delineated by the extent of the isolating series of the Tertiary formation (Figure 1).

Coal mines have caused drainage of the Carboniferous water-bearing rocks. The Triassic and Quaternary aquifers are drained too in the first hydrogeological region, locally in the second region. The areas of decreased piezometric pressures occupy about 1720 $km^2$.

Differentiation of the present hydrogeological setting within the USCB depends on two fundamental factors, i.e. geological conditions and the extent of mine workings in the Carboniferous formation.

The block-tectonics is an important factor in formation of underground water regime. The hydrogeological investigations carried out in the excavations of the hard coal mines have shown that the fault zones can form both impermeable or semipermeable hydrodynamic barriers as well as preferred flow routes of water, depend on their permeability (Wilk, 1960). The regional fault zones, according to current investigations are the zones of regional drainage of waters occurring in the Carboniferous formation.

The different lithological development of four main lithographic series of the Upper Carboniferous is an important factor in formation of water-bearing capacity of the rocks and permeability in the Carboniferous formation profile. The series are composed of sandstones, conglomerates, siltstones and claystones but the share of water-bearing formations in the series varies from 16% to 85%.

The basic factor is the tendency to decreasing of hydrogeological properties of water-bearing rocks with the increasing depth. The Carboniferous sandstones are practically impermeable and no water-bearing at the great depth (Różkowski, 1995, 1999; Wagner, 1998). This phenomenon is connected with process of rock diagenesis. Its intensity increases with depth. The permeability of the Carboniferous sandstones in the depth interval from 100 m to 2,000 m decreases from 1.400 mD to 0.005 mD (Różkowski,1999). It does not concern the areas of mining where slide, cracks and unstressing of rocks accompanying mining excavation cause increase of rock permeability.

The isolating role of the Tertiary clayey formation is of essential importance. This formation creates the main hydrodynamical and hydrochemical barrier in the hydrogeological section of the USCB.

The Tertiary gypsum and salt deposits in the north-western part of the USCB also play an important role in formation of mineralization and chemical composition of groundwater. It refers mainly to Miocene salt-bearing deposits situated in the Zawada graben in the western part of the USCB. They greatly affect chemical composition of groundwater in the Tertiary and Carboniferous formations in the deposits vicinity (Figure 1).

Underground coal mining have caused the disturbances of the natural hydrogeological conditions including the drainage of rocks, alternation of water chemistry and flow directions and velocity as well as the changes of heads. Slides, cracks, and stressing of the rocks usually accompany mining activities. These processes cause increase of the rock permeability and the hydraulic connection of water from different aquifers, producing the interruption of isolating layers. The size of drainage is determined by a geological structure, surface and depth of mining works and the range of a formed depression.

Coal mining predominates in the first hydrogeological region (I). Its direct impact on the water resources is manifested by drainage of the Carboniferous formation and the overburden Quaternary and Triassic aquifers. In the second hydrogeological region (II) the Carboniferous water-bearing sandstones as well as, in the small amount, the Tertiary and Quaternary aquifers are drained under impact of coal mining.

## 5 CHEMISTRY OF MINE WATER

Mine water is pumped out from 50 coal mines in total quantity of 692 $m^3$/min. TDS of natural mine water ranges from 0.2 to 372 g/l, but the cumulative pumped out water mineralization is from a few up to 110 g/l. Differentiation of the present chemical composition and total mineralization of mine water in the interval of exploitation depth up to 1200 m under surface depends on geological setting, groundwater flow systems and mining activity. In the case of mining activity, the size and depth of mining as well as duration of coal exploitation should be taken into account. The artificial hydraulic interconnection created by mine workings and deep drainage cause the changes in the natural chemistry and quality of groundwater mainly due to water mixing processes. Forming of groundwater chemical composition undergoes the continual changes during mine exploitation.

Mine waters are highly variable in their chemical composition and TDS. There is a special chemical classification of mine waters which takes into account processes of these water utilization. According to this classification (Rogoż, 1995), the pumped out mine waters belong to different chemical groups taking into account the following quantities:

1) water with TDS below 1.0 g/l and the content of Cl and $SO_4$ ions below 0.6 g/l (fresh water) - 268.7 $m^3$/min;
2) water with TDS from 1.0 g/l to 3.0 g/l and the content of the Cl and $SO_4$ ions from 0.6 g/l to 1.8 g/l (industrial water) - 175.2 $m^3$/min;
3) water with TDS from 3.0 to 70 g/l and the content of the Cl and $SO_4$ ions from 1.8g/l to 42 g/l - (saline water) - 200.2 $m^3$/min;
4) water with TDS above 70 g/l and the content of the Cl and $SO_4$ ions from above 42 g/l (brines) - 47.9 $m^3$/min.

According to these numbers, the first group of water quality - fresh water - dominates among the groundwaters inflowing to mines (39%). The industrial water (the second group), saline water (the third group) and brines (the fourth group) represent 25%, 29% and 7% of the total amount of groundwater inflow, respectively. Deep mines pump out waters of all mineralization groups.

There is the close relationship between the amount of inflow of the particular mineralization group of water to a mine and kind of overburden of the productive Carboniferous formation. The inflow of fresh water is about 188 $m^3$/min in case of mines situated in the areas where Carboniferous formation is covered by the Quaternary deposits (70%), 37 $m^3$/min (44%) where the Triassic carbonate sediments occur in overburden, and 43 $m^3$/min (16%) where permeability of overburden is various.

Fresh and industrial water does not occur in the mines which are exploiting hard coal under thick isolating Tertiary overburden. Saline water and brines occur in the mines independently of the kind of the productive Carboniferous overburden. It means that the inflow of brines to the mines takes place in the first hydrogeological region as well as in the second one.

There is a general trend of increasing mine water mineralization with depths, independently of the age of rocks (Figure 2). The mine water chemical data demonstrate a vertical succession of hydrochemical zones in the Carboniferous strata. Three hydrochemical zones have been distinguished: the zone of infiltration water, the intermediate zone of mixed water, and the lower zone of relict brines (Różkowski,1995; Wagner, 1998). These zones are defined on the basis of the value of hydrochemical coefficients and total mineralization of mine water as well as their gaseous and isotope content (Różkowski, 1995, 1999).

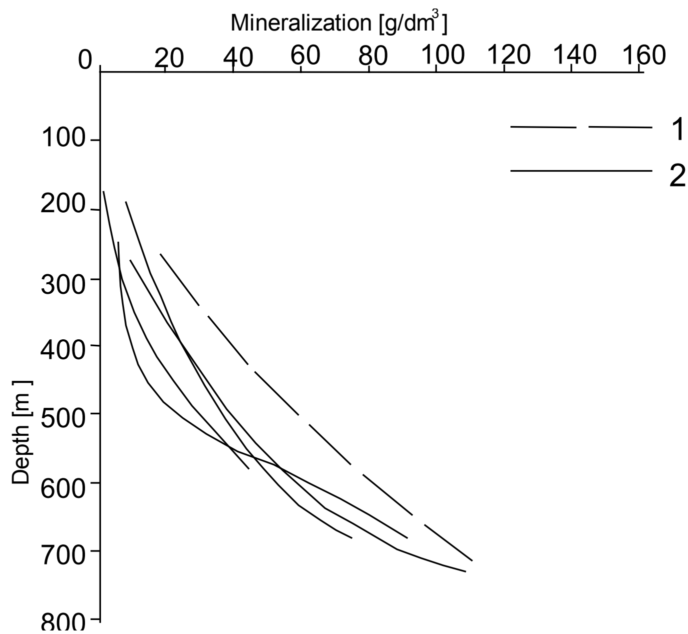


Figure 2 Dependence of the groundwaters mineralization on the depth of sampling (II hydrogeological region
*1 - groundwater mineralization before mining; 2 – groundwater mineralization of mine waters.*

The zone of infiltration water reaches the depth of about 300 m in the first hydrogeological region and about 80 m in the second one. The lower boundary of the mixed water zone lies at the depth of 450 - 650 m at maximum in the first hydrogeological region. In the second one, the lower boundary of this zone lies at the depth of about 240 m. The zone of relict groundwater underlies the mixed water zone. Hydrochemical studies of mine water have shown that brines with TDS above 35 g/l occur at the depth 650 - 850 m in the USCB, depending on the varying geological setting and mining activity in the individual geological structures.

Stable isotope data allow to assume that in the first zone there is meteoric water of the last infiltration period, in the second one there are mixed infiltration and paleoinfiltration waters, and in the zone of relict brines there are paleoinfiltration waters of different age (Różkowski, 1995; Zuber & Pluta, 1989).

According to the recent studies, taking into account the mining classification as well as hydrochemical zonation, fresh and industrial waters occur in the infiltration groundwater zone, saline water belongs to the mixed water and partly to relict brine zones, and mineralized brines occur in the zone of relict brines.

Fresh and industrial waters occurring in the infiltration water zone are formed in the different geological formations and under variable human impact, hence the chemistry and quality of waters are various. These waters occur almost only in the first hydrogeological region. Fresh and industrial waters (TDS below 3 g/l) are mainly of hydrochemical types: $HCO_3$-Ca, $HCO_3$- $SO_4$-Ca, $SO_4$-$HCO_3$-Ca-Mg, Cl-$HCO_3$-Na. Their hydrochemical coefficients show values: r(NaCl) above 1, r(Ca/Mg) above 1 and r(100*$SO_4$/Cl) above 1. The industrial mine waters belong mainly to brackish waters.

These waters are enriched in sulphate ion in the mining workings, due to oxidation of pyrites and sulphur in coal seams. Nitrogen predominates in gaseous composition of mine waters of the infiltration zone. The described waters occur in the oxidation zone. Under the cover of the Triassic carbonate formation, coal mine waters are of the $HCO_3$-Ca-Mg and $HCO_3$-$SO_4$-Ca hydrochemical types. Waters infiltrating to the coal mines from the Quaternary aquifers are usually of the $HCO_3$- Ca and $HCO_3$-$SO_4$- Ca types. In the areas of the maximum influence of the urban-industrial agglomeration on the environment, waters are degraded additionally by pollution migrating from the surface. From the chemical point of view these waters are mainly of $SO_4$-$HCO_3$-Ca-Mg types with TDS ranging from 1.5 g/l to 5.3 g/l. Since vulnerability of the Carboniferous aquifers to anthropogenic pollution is high due to high exposure and mining activity the quality of mine waters is poor in the infiltration zone.

Saline waters with TDS from 3 g/l to 70 g/l (according to the Polish mining classification) belong mainly to Cl-$HCO_3$-Na and Cl-Na hydrochemical types. The following values of coefficients are typical for them: r(Na/Cl) from 1.3 to 0.87 and r(100*$SO_4$/Cl) from 0.007 to 9.1. Nitrogen predominates in the upper part of their occurence and methane predominates in the lower one. This evidence allows to assume that saline waters may occur in the oxidation as well as in the reduction zones. There is the observed increase of the mixed water zone thickness zone due to desalination processes of mine brines during exploitation period.

The highly mineralized mine waters belong to the relict brine zone with TDS above 70 g/l and to hydrochemical types Cl-Na and Cl-Na-Ca. They have the following values of hydrochemical coefficients: r(Na/Cl) from 0.72 to 0.86 and r(100*$SO_4$/Cl) below 1. They occur in the reduction zone only. The brines occurring in the Carboniferous sediments in vicinity of the Tertiary salt deposits are of the Cl-Na hydrochemical type and value of their r(Na/Cl) coefficient is 0.96. Highly mineralized waters in insulated structures are buried brines of the Cl-Na-Ca type. Methane from degassing of coal seams predominates in gaseous composition of those brines.

Desalination of groundwater caused by mining impact has been observed in both hydrogeological regions of the USCB. In the first region the long-time mining has made the rocks more permeable and has lowered the drainage base of the gravitational groundwater flow system. It enabled more effective infiltration of atmospheric waters through the permeable overburden in the bed-rock. The hydrochemical gradient of mine waters in the depth interval to 450 m varies from 0.9 to 4.4 g/l/100 m, while before mining the average value of it was 8.8 g/l/100. In the case of the second region this phenomenon is connected with the active drainage effect of less mineralized waters from the Tertiary formation and from the upper links of the Carboniferous formation. The distinct decrease of mineralization of mine water in the case of coal extraction at the depth below 750 m has not been observed very clearly (Figure 2).

The distinct tendency to desalination of mine waters over time is connected with long-lasting exploitation at the individual working levels. The example is illustrated in Figure 3 showing the changes in mineralization of groundwater inflowing to the working level 550 of the Budryk mine in 1974-1991. Wide-front cut of deposit made in the seventies has led to drainage of the basic resources of the static relict waters. At the beginning of the eighties, renewed increase of water inflowing to the mentioned mineralization level has been caused by cut of the new parts of the deposit. And then it can be observed again the distinct tendency to desalination of mine water.

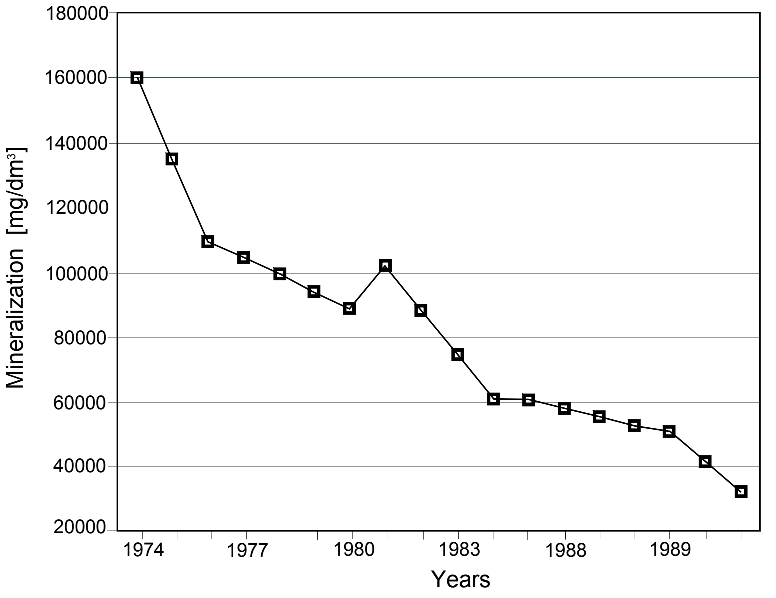


Figure 3 Changes of mineralization of water inflowing to the working level 550 of the Budryk mine

## 6 CONCLUSIONS

At present there are 50 active coal mines in the Polish part of the USCB. The coal fields cover the area of about 2000 sq. km. The depth of mining works varies from 300 m to 1200 m. Mine water is pumped out from coal mines in total quantity of 692 $m^3$/min. TDS of natural mine water ranges from 0.2 to 372 g/l but the cumulative pumped out water mineralization is from a few to 110 g/l. Mine water is highly variable in its chemical composition and TDS. Geological structure, recharge conditions of the Carboniferous water-bearing sandstones and the mining activities have influenced the chemical variability of mine water. There is a general trend of increasing mine water mineralization with depth. Recently, there is observed the distinct tendency to desalination of mine water over time connected with long-lasting exploitation.

## REFERENCES


Kotas A., ed., 1994. Coal-bed methane potential of the Upper Silesian Coal Basin, Poland. *Prace Państwowego Instytutu Geologicznego CXLII.* Warszawa.

Rogoż M., 1995. Current problems of hard coal mining hydrogeology (in Polish). In*:* *Współczesne problemy hydrogeologii.* 7, cz. 2: 21-30. Kraków-Krynica.

Różkowski A., 1995. Factors controlling the groundwater conditions of the Carboniferous strata in the Upper Silesian Coal Basin, Poland. *Annales Societatis Geologorum Poloniae* (1995), vol. 64, 53-66.

Różkowski A., 1999. Origin of mine waters based on the isotopic and chemical composition (Upper Silesian Coal Basin, Poland). *Mine, Water & Environment*. 1999 IMWA Congress, Sevilla, Spain, 99-105.

Wagner J., 1998. Hydrogeological characterization of the Carboniferous productive sequence in the main trough of the Upper Silesian Coal Basin (in Polish, English summary). *Biuletyn Państwowego Instytutu Geologicznego* 383:, 55-96.

Wilk Z., 1960. Inundation of Upper Silesian coal mines in relation to geological conditions and depth and size of mine (in Polish, English summary). In*:* *Geotechnika i hydrogeologia*. Zeszyt 1a: 8-44. Geopol Przedsiębiorstwo Geologiczno-Inżynierskie Energetyki - Kraków. Wydawnictwa Geologiczne, Warszawa.

Zuber A. & Pluta I., 1989. Origin of brines in the Upper Silesian coal basin (in Polish, English summary) . *Prace nauk. Inst. Geol. Pol. Wr.,* 58: 497-504, Wrocław.


## Chemizm wód podziemnych pompowanych z kopalń węgla kamiennego GZW i jego zmiany w wieloleciu


Andrzej Różkowski



**Streszczenie:** Kopalnie węgla kamiennego zlokalizowane w zasięgu GZW pompują ok.990 tys. $m^3$/dobę wód podziemnych o mineralizacji zmiennej od 0,5 g/$dm^3$ do 327 g/$dm^3$. Ilość, a przede wszystkim mineralizacja i skład chemiczny

dopływających do kopalń wód podziemnych, są uzależnione głównie od wykształcenia i miąższości utworów nadkładu oraz głębokości, systemu i czasu prowadzonej eksploatacji. W związku z wyczerpywaniem się zasobów złóż węgla obserwuje się wzrost głębokości prowadzonej eksploatacji. Maksymalne głębokości eksploatacji górniczej w poszczególnych kopalniach w 1957 roku wahały się w granicach od 200 do 400 m, zaś obecnie – od 400 do 1200 m. Wraz ze wzrostem głębokości eksploatacji zwiększyła się na przestrzeni kilkudziesięciu lat ogólna mineralizacja wód pompowanych z kopalń od 4,9 $g/dm^3$ do 11 $g/dm^3$ . Zjawisko to wiąże się z ogólnym trendem wzrostu zasolenia wód podziemnych występujących w utworach karbonu z głębokością. Skład chemiczny wód kopalnianych ulega stałej ewolucji uzależnionej od rozwoju eksploatacji.