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HYDROGEOLOGICAL CONDITIONS OF THE CRACOW SANDSTONE SERIES IN UPPER SILESIAN COAL BASIN INFLUENCED BY MINING ACTIVITY

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Abstract. The Cracow Sandstone Series (CSS), consisting mainly of coarse-grained clastic rocks (>75%), form upper lithostratigraphic series of the coal-bearing Carboniferous formations in the Upper Silesian Coal Basin (USCB). CSS covers the area of 1,500 km^2. Thicknes of a formation varies from tens to 1,140 m. Exploitation of coal deposits on industrial scale of production has started since the turn of the XVIII and XIX century. Intensity of water inflows to individual mines ranging from 4.3 to 52.8 m^3/min, depends on morphological, geogenic and mining factors. Within the CSS hydrogeological complex typical for sedimentary basins hydrodynamic and hydrogeochemical vertical zoning occurs. Hydrochemical as well as isotope research revealed appearance of varied zones of infiltration, mixed waters and relict brines. Prevailing significance in hydrodynamic conditions forming within the CSS have hydrodynamic barriers: overlying isolating Miocene aquitard and increasing with depth diagenesis of the Carboniferous formation. The mining activity increases the rock permeability and causes the disturbance of the natural hydrodynamic field and hydrogeochemical conditions of the CSS.

Key words: mining activity, hydrogeological conditions, Cracow Sandstone Series, Upper Silesian Coal Basin.

GEOLOGICAL CONDITIONS AND MINING ACTIVITY

The Cracow Sandstone Series (CSS) form the upper lithostratigraphic series of the coal-bearing Carboniferous formations (Westphalian B, C, D) in the Upper Silesian Coal Basin (USCB). The CSS profile is represented by: Libiąż strata, Łaziska strata as well as the top series of Orzesze strata till the 303 bed (Kotas, 1985). The CSS is composed mainly of coarse-grained clastic rocks (sandstones and conglomerates), interbedded with siltstone and claystone deposits accompanying coal seams. The share of coarse-grained sediments exceeds 75% of a series profile.

The Cracow Sandstone Series occurs in the central and eastern parts of the Upper Silesian Coal Basin (USCB) (Fig 1). It covers the area of about 1,500 km^2. The total thickness of the formation is variable, ranging from tens to 1,140 m. The roof of a series lies on the depth changing from 320 to –720 m above sea level. The basement of the CSS is formed by the Mudstone Series of the Upper Carboniferous. An area of the CSS extent characterizes block tectonics. The southern and central parts are within the reach of the Carpathian Fordeep, where sediments are covered with the clayey formation of Miocene. The northern part of the CSS area, lies in range of the epi-Variscean platform as well as Mesozoic platform cover (Cracow–Silesian Monocline). The overlying formations are of the Quaternary, Triassic and locally Jurassic age. Maximal thickness of the Quaternary deposits, up to tens of meters, was recognized in present as well as

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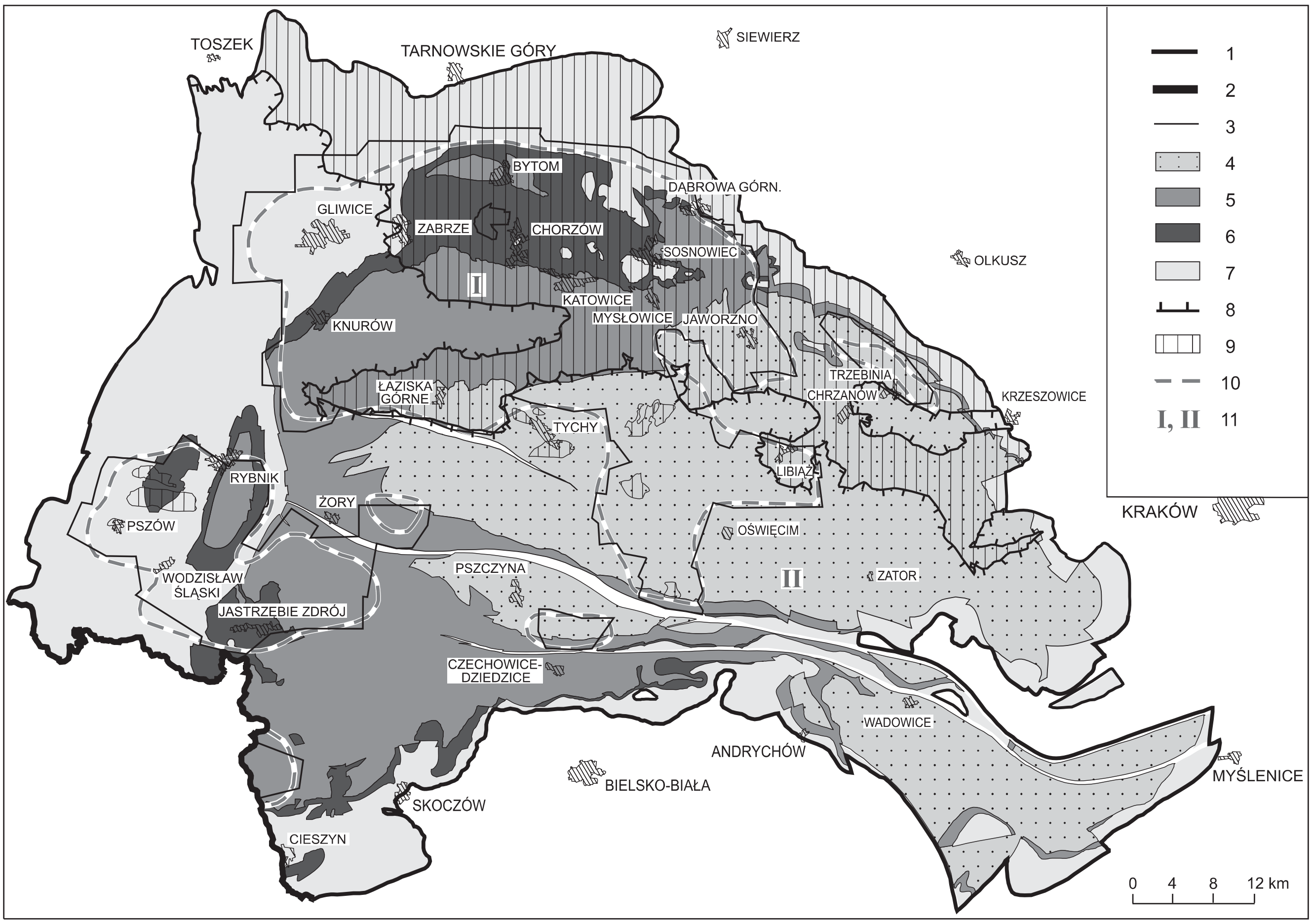

Fig. 1. Hydrogeological map of the Upper Silesian Coal Basin (USCB)

1 – extension of the USCB, 2 – state border, 3 – extension of the coal mine mining areas, 4 – Cracow Sandstone Series (CSS), 5 – Mudstone Series (MS), 6 – Upper Silesian Sandstone Series (USSS), 7 – Paralic Series (PS), 8 – extension of the isolating series of the Miocene formation, 9 – recharge areas of the Carboniferous aquifers, 10 – extension of the mining drainage in the productive Carboniferous formations, 11 – hydrogeological subregions

buried valleys of the Vistula and Przemsza rivers. Exploitation of coal deposits on industrial scale of production has started since the turn of the XVIII and XIX century. At the beginning exploitation concentrated exclusively at the outcrops, carried out with both basic mining methods: surface and underground, where opening out was realized by dip-headings. With the development of mining techniques and exhaustion of coal seams close to the surface, begun an underground exploitation, below the groundwater level. The depth of mining works varies from 270 to about 600 m. Due to the great number of mineable coal seams in the sequence, exploitation is carried out simultaneously at several depth levels. Coal extraction is realized by longwall mining technique with roof collapse. Localization of mining areas within the CSS extent is shown on Figure 2.

The water inflow to the mines depends on conducted mining works and accompanying drainage of the Carboniferous formation as well as its overburden. Mines exploiting coal seams within the CSS characterize with total inflows in range from a few to tens of m^3/min. High classes (III, IV) of water flooding predominate. Maximal individual inflow to a single mine ranging from 26.8 to 52.8 m^3/min (Jan Kanty, Jaworzno, Siersza, Ziemowit mines), results from proximity of present and buried river valleys in the northeastern part of the USCB. Water inflows to the mining works localized on an area of the Carpathian Fordeep amount from 4.3 to 10.6 m^3/min (Silesia and Brzeszcze mines). A tendency of water inflow decreasing to specific extraction levels with increasing depth was observed (Wilk, ed., 2003). The total inflow amount depends on morphological, geogenic factors, as well as time and technique of exploitation and an area of underground workings (Rogoż, Posyłek, 2000; Wilk, ed., 2003). Since 1989 a process of mining industry restructuring has began. Some of mining works were closed, the others only in part, including ones exploiting coal seams from the CSS.

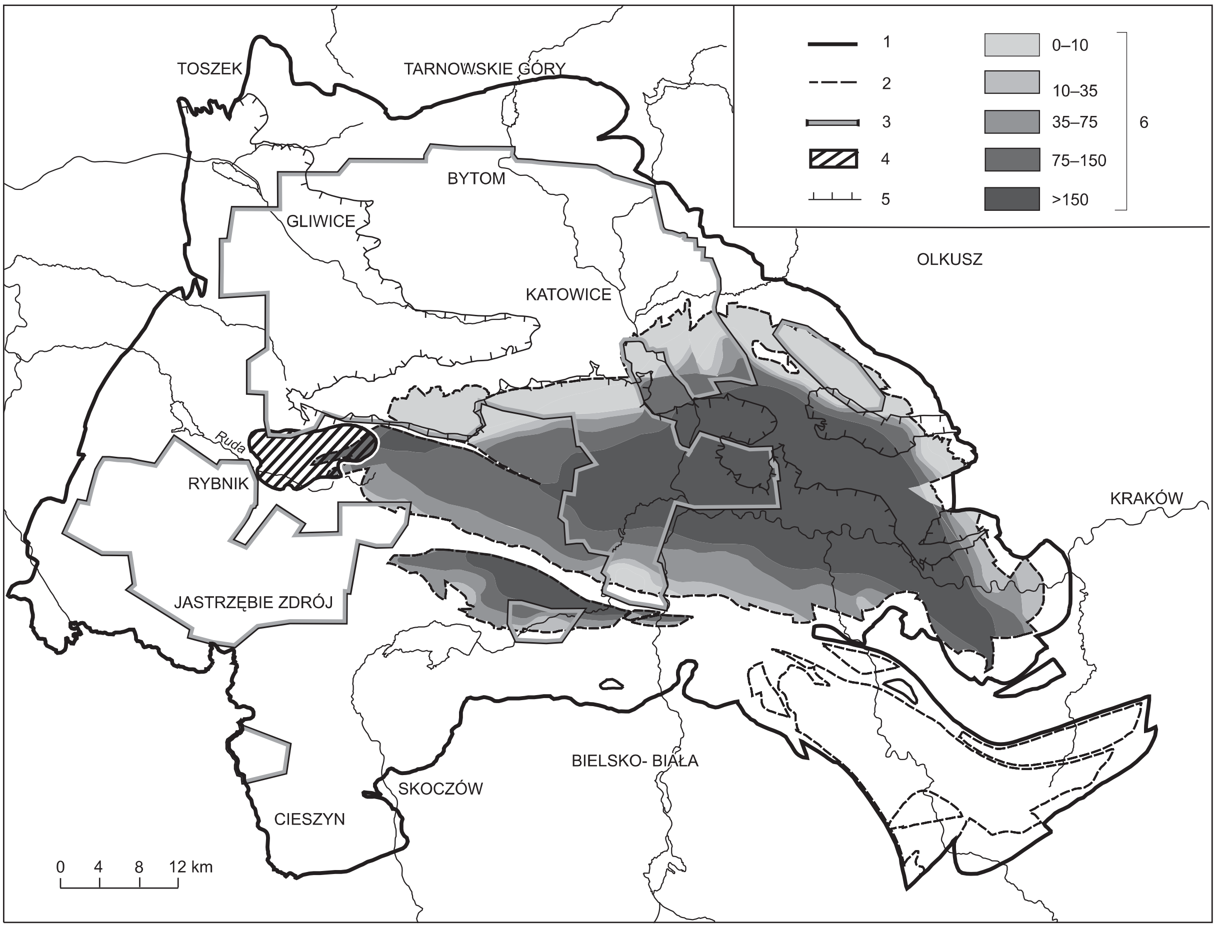

Fig. 2. Hydrochemical sketch-map of the Cracow Sandstones Series (CSS)

1 – extension of the productive Carboniferous formation in the Polish part of the USCB, 2 – extension of the CSS, 3 – extension of the coal mine mining areas, 4 – salt deposit in the Miocene formation, 5 – extension of the isolating series of the Miocene formation, 6 – mineralization (TDS) and hydrochemical types of groundwater in the sole part of the CSS: 0–10 g/dm^3 multi-ion types; 10–35 g/dm^3 multi-ion types; 35–75 g/dm^3 Cl–Na type; 75–150 g/dm^3 Cl–Na, Cl–Na–Ca types; >150 g/dm^3 Cl–Na, Cl–Na–Ca types

HYDROGEOLOGICAL ENVIRONMENT OF THE CRACOW SANDSTONE SERIES

The geological structure of the USCB is diversified. The Paleozoic block structure in the northeastern part of the USCB is treated as the main recharge area of the Carboniferous hydraulic systems due to their hypsometric position and occurrence of permeable Mesozoic and Quaternary overburden. Syncline structures in the southern part of the Carboniferous basin, under impermeable Miocene cover, constitute the hydrogeological complex with defined flow routes and discharge areas. It is an area where high piezometric pressures are formed.

Taking into account the hydraulic structures of the USCB, two hydrogeological subregions: the northeastern (I) and southwestern (II) of different hydrogeological conditions have been distinguished (Fig. 2). Their boundaries are delineated by the extent of the isolating series of the Miocene formation.

The Quaternary and Triassic aquifers present in an overburden of the first subregion are in hydraulic connection with Carboniferous water-bearing horizons (Fig. 1). An area of the southwestern (II) subregion has isolating the Miocene formation covering the Carboniferous strata. It is an area where high piezometric pressures are formed. Locally the recharge takes place at the areas where Miocene sediments were eroded or their thickness is very low.

The CSS hydrogeological complex belongs in its northeastern part to the first subregion, while the south of the area spread out over the limits of the second one (A. Różkowski, K. Różkowski, 2003). In a hydrogeological profile of a complex prevail water-bearing sandstones and conglomerates of thickness attaining up to 24 m. Claystones and siltstones are reduced to a thin 0.05–6.20 m isolating intercalations. Isolation has not a continuous character, according to petering out of series and dislocation of rock mass. Results of field and laboratory research of the CSS sandstones and conglomerates hydrogeological properties examined in an interval up to 1,200 m were published among other things by Kleczkowski, Witczak (1967), Kleczkowski, Wilk (1968), Witkowski

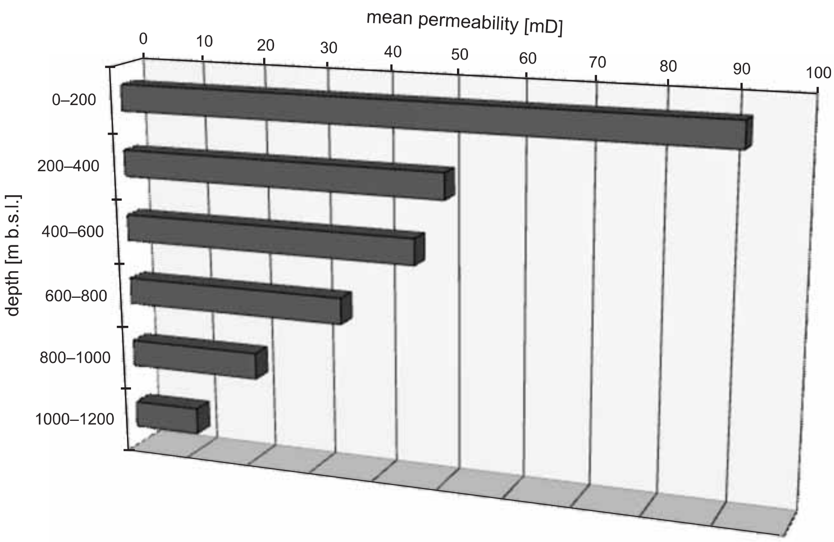

Fig. 3. Variation of permeability of CSS water-bearing strata with depth in a division to 200 m intervals (laboratory studies)

(1982), Wagner (1998) and A. Różkowski (2003). Analysis and summary of the research was recently presented in the paper of K. Różkowski and Witkowski (2004).

Conducted studies revealed high variability of hydraulic conductivity from $5.0 \cdot 10^{-8}$ to $3.3 \cdot 10^{-4}$ m/s, of falling tendency with increasing depth. Considerable decrease of sandstones filtration properties with depth was confirmed by laboratory determination of rock permeability (Fig. 3).

Effective porosity of coarse-grained clastic rocks reduces adequate to depth from 31.7 to 4.6%, while specific yield from 10.0 to 1.6% (K. Różkowski, Witkowski, 2004).

Results of field and especially laboratory research enabled a determination of general natural model and mechanisms of hydrogeological rock properties variability in a geological Carboniferous profile. They are related to only a few primary factors. Among them are: 1) structural and textural diversity of sandstones as well as variability of mineralogical composition and cementing material, 2) diversity of spatial shapes and sizes of pores as well as their specific surface and volume, 3) increase of hydrogeological parameters values with grain diameter size (Witkowski, 1982). Very important factor is also diagenesis degree of rock mass.

Observed elevated values of hydrogeological parameters in the roof series of the CSS should be linked first of all with intensified activity of mechanical and chemical weathering processes in common sense, at the outcrop areas. Decrease of obtained results of studies with depth is connected with progressing processes of deposits diagenesis and cementation.

As a result of the mining activity increases the transmissivity of rock massif as well as a storage capacity and permeability. Research conducted by Bukowski (1999) and Rogoż, Posyłek (2000) revealed that transformed water storage capacity of rock mass is multiplied in comparison to natural conditions. Within the zone of mining activity in range of the CSS area and depth interval to 200–400 m below surface, formed an anthropogenic complex of high water-bearing capacity and permeability. The complex is in hydraulic connection with overlaying aquifers and is actively drained by mining.

Water bearing-capacity of sandstones represented by specific discharge of wells varies with depth from 10.25 m^3/h/1mS at the depth of about 60 m to 0.004 m^3/h/1mS at the depth of 850 m. Within the outcrops of the CSS extent, where erosion and rock relaxation take place, water storage capacity is higher due to fissuring of rocks to the depth of about 400 m.

According to Toth's theory (1995) it can be assumed, that in the extent of the whole Upper Silesian Carboniferous sedimentary basin, in comparison to other similar structures, groundwaters under the conditions of gravitational flow pattern, are in mutual hydraulic connection, independently from depth of rock mass deposition and permeability. As a consequence of water percolation forms a regional flow system of a great extent, in range of which transitional and local flow systems exist (A. Różkowski, ed., 2004).

The hydrodynamic field of the CSS water-bearing complex forms in s synclinal structure with the defined water flow patterns and determined recharge and drainage areas. Under natural conditions, not disturbed by mining activity, river valleys, wells and regional dislocation zones formed the base of gravitational flow system drainage.

At present, the CSS water-bearing complex is drained mainly by mining workings, less often by regional dislocation zones. At the outcrop areas drainage is realized by river valleys and single wells. Intensive mine drainage formed vast and deep depression zones of diminished piezometric pressure to about 4.0 MPa (Fig. 1).

Natural hydrogeological environment of the CSS has been transformed at the areas of mining activity influence (Wilk, 1965; Rogoż, Posyłek, 2000; Wilk, ed., 2003). Mining exploitation leads to surface subsidence over exploited beds what causes breakings down, fracturing and rock mass relaxation implicating increase of transmissivity and formation of hydraulic connection between water-bearing horizons on a large scale. Dewatering of mine galleries causes rock mass drainage and simultaneous drop of groundwater level in the CSS structure. Hydraulic gradients, directions and velocity of groundwaters flow are altered. High value of underground runoff module in range from 3.5 to locally 11.0 l/s/km^2 for mining areas is a measure of drainage intensity and water infiltration. Mining drainage causes also direct draining and decrease of water resources of overlying aquifers. Locally can be observed changes of water-courses character, from draining to recharging. These processes induce changes in surface catchment hydrologic balance.

The isotopic investigations of waters sampled from mines of the I subregion (mines: Ziemowit, Janina, Jaworzno, Siersza) revealed deep infiltration of atmospheric waters into the CSS rock mass, reaching the depth of about 400 m (A. Różkowski, ed., 2004). The results of Tritium content examination in mine waters from the Carboniferous outcrops under the cover of Quaternary and Triassic sediments (I subregion) have shown that the process of atmospheric water infiltration is progressing in time (A. Różkowski, 1998). This phenomenon is connected with increasing in time depth and area of rock mass cut by mining activity and active water drainage.

At present, at the time of mining industry restructuring, some of the mines are partially or completely closed. Cessation of mine workings dewatering causes gradual self-flooding of extracting levels and partial filling of depression cone by underground recharge as well as infiltration of atmospheric precipitation. Progressive reconstruction of pressure field in the CSS complex and change of mine waters chemical composition takes place. This process is slow and long-lasting.

CHEMICAL COMPOSITION, GENESIS OF GROUNDWATERS AND HYDROCHEMICAL ZONALITY

Total water mineralization within the CSS formation expressed as TDS varies between 0.12 and 179.15 g/dm^3. There is observed a general trend of water total mineralization increase with depth as well as a change of ion mutual relations (Fig. 4).

Analysis of hydrochemical investigations has shown an occurrence within the CSS hydrostructure of vertical, regional zonality, typical for sedimentary basins (A. Różkowski, ed., 2004). On the base of chemical composition and hydrochemical indices of groundwaters were distinguished three

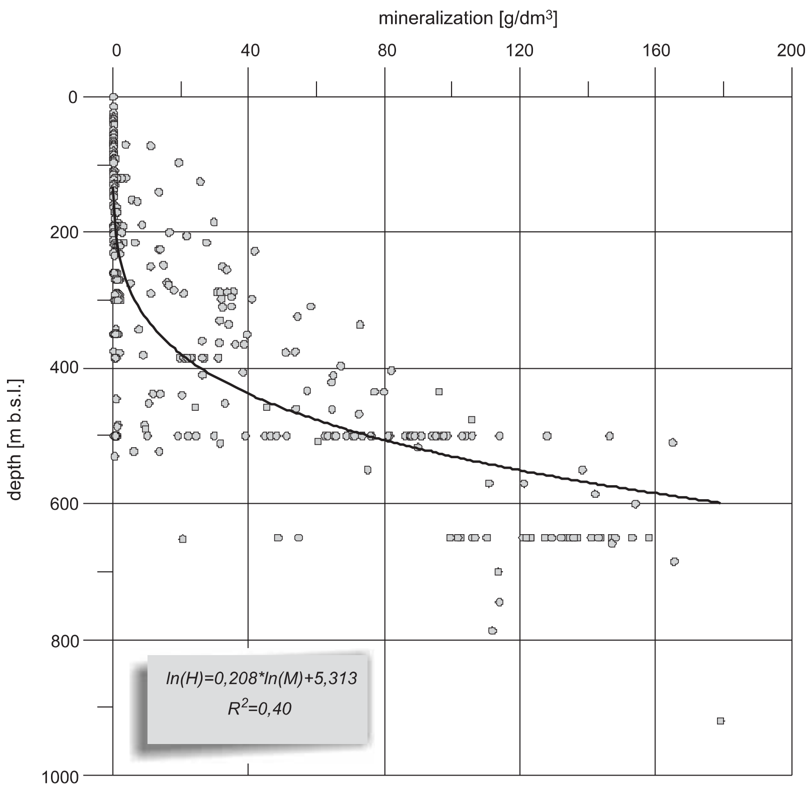

Fig. 4. Increase of groundwater mineralization with depth in the CSS hydrogeological complex

hydrochemical zones in vertical profile of the CSS, which are in correlation with hydrodynamic zones (A. Różkowski, ed., 2004; K. Różkowski, 2004). A zone of active water exchange is in correlation with hydrochemical zone of infiltration waters, intermediate zone – with hydrochemical zone of mixed waters, zone of hydrodynamic stagnancy – with zone of relict brines. In a relation to geological structure, hydrodynamic conditions and intensity of mining exploitation, vertical thickness of hydrochemical zones differs in both subregions and even within their boundaries as well as varies in time.

The results of isotope investigations confirmed occurrence of these three hydrochemical zones in hydrogeological profile of the CSS (A. Różkowski, ed., 2004). Zone of infiltration waters is characterized by isotope values: $\delta^{18}O$ –11.7 to –9.0 per mille and δD –80.0 to 67.9 per mille. Waters of this zone with mineralization from 0.5 to 3.6 g/dm^3 occur in the first subregion in depth interval up to 410 m. In gaseous composition of waters there are atmospheric gases. Zone of mixed waters with a mineralization from a dozen or so to 62.7 g/dm^3 characterizes with isotope values as follows: $\delta^{18}O$ –8.8 to –8.2 per mille and δD –67 to –61 per mille. Nitrogen is dominant in these waters in the upper part of their occurrence and methane – in the lower one. Such results point out that these waters occur in both oxidizing and reduction zone.

Relict waters occurring at the depth under 650 m have isotope values: $\delta^{18}O$ –6.30 to –3.80 and δD –49.0 to –36.0 per mille, while their mineralization varies from 79.9 to 149.8 g/dm^3. Brines with TDS values exceeding 35 g/dm^3 belong to hydrochemical types Cl–Na and Cl–Na–Ca (Fig. 2). They occur only in reduction zone. In their gaseous composition dominate methane originating from coal seams.

Conducted investigations proved a presence of regional hydrochemical zoning characterized by changes of total mineralization and chemical composition of waters along their flow routes (Fig. 2). The studies revealed a general tendency of water mineralization increase with depth, independently from the age of water-bearing sediments, as well as a change of water ion composition in conformity with sequence: $HCO_3 \rightarrow SO_4 \rightarrow Cl$ (Fig. 4). The basic importance for hydrochemical zonation forming in the CSS aquifer have thickness and permeability of overburden strata, total thickness of the Carboniferous complex and a degree of sediment diagenesis, as well as an activity of coal mines.

In order to present general rules of the regional hydrochemical zoning formation in the CSS hydrogeological complex there were investigated changes of mineralization and chemical composition of waters along their flow routes (K. Różkowski, 2004). The analyses underwent waters from the floor strata of a complex.

The analysis of spatial distribution of mineralization zones has shown an occurrence of waters with mineralization from 0.3 to 10.0 g/dm^3 within the first hydrochemical subregion and locally in the second one, in recharge zones of the CSS complex. Multi-ion waters predominate, with a supremacy of HCO_3 and SO_4 ions. In a zone of waters with TDS from 5 to 10 g/dm^3, in an ionic water composition dominate chlorides and seldom sulfates. In the second hydrogeological subregion, in an intermediate and stagnant zones, water mineralization increases along the flow routes. At first highly mineralized waters are present, replaced afterwards by brines of Cl–Na and Cl–Na–Ca types.

Mining activity constitute a fundamental factor forming present hydrodynamic field of the CSS (A. Różkowski, ed., 2004; Pluta, 2005). Physical and chemical processes influencing the chemistry of mine waters proceed in a dynamic system, changeable in time and space. The basic influence on modification of physical and chemical composition of mine waters have following factors: 1) deepening infiltration of waters from overlying strata, 2) mixing of waters from connected by mine exploitation aquifers, 3) water interaction with geochemically altered rock matrix, 4) ascension of brines through the dislocation zones. In some cases pollution of mine waters can be caused by storage of exploitation wastes on surface and in excavations as well as by introducing of technological waters into mine workings. Desalinization of mine waters in time is in general a main result of the intensive drainage. This process is especially intensive at the areas of the Carboniferous aquifer recharge.

Mine waters sampled in the mine workings within the CSS rock mass are diversified in their chemical composition, total mineralization and genesis. Isotopic investigations of natural mine waters have shown a variation in obtained values in limits: $\delta^{18}O$ –11.18 to –3.80 per mille and δD –80.0 to –36.0 per mille. This data shows that sampled mine waters belong to the group of contemporary infiltration waters, but also mixed and relict ones (A. Różkowski, ed., 2004). Taking into account geological, structural, hydrogeological and mining criteria, there was prepared a hydrochemical regionalization of mining areas (A. Różkowski, Sołtysiak, 2005). An area of the CSS occurrence belongs to the Łaziska–Siersza–Dąbrowa hydrochemical region (of the first subregion) and the region of the northern part of the USBC main syncline (the second subregion).

The investigations carried out in the mines: Jaworzno, Piast, Ziemowit and Janina, situated in the extent of hydrochemical region of the first subregion, have shown occurrence of multi-ion infiltration waters with mineralization of a few grams to the depth of about 400 m. Multi-ion and chloride waters with higher mineralization occur in a zone of mixed water, up to the depth of about 600 m. Underneath brines typical for stagnant zone are present. In the second hydrochemical region investigations of mine waters were carried out in the mine workings of: Brzeszcze, Czeczot and Silesia mines. This region characterizes with variable chemical composition of mine waters and depth of their occurrence. Mentioned conditions result from the degree of the CSS sediments isolation and the range and time of mining exploitation. Zone of infiltration and mixed waters with mineralization from a few to 22.5 g/dm^3 was investigated at the depth of 300–400 m, locally deeper. Underneath 400 m brines occur as a rule. Process of partial or complete liquidation of mine workings by self-flooding, influences a change of chemical composition and physical properties of mine waters.

Physical and chemical processes in abandoned mine workings have special meaning. They proceed dynamically in the variable arrangement of hydrodynamic field. Results of investigations carried by Janson (2007) have shown that observed changes of pumped waters chemical composition are strictly connected with exploitation technology and mine workings liquidation technique and especially with variations of accumulated groundwater level in abandoned workings. Hydrochemical processes in a rock mass under the mining drainage are connected mainly with oxidizing of metal sulfides, especially of pyrite and marcasite. In result of this processes increases the concentration of sulfates, metals and among them total iron, water hardness, suspension level and decreases the pH of water. Pluta's (2005) investigations have shown that in specific mines, in favorable hydrogeochemical environment, oxidizing of sulfide minerals in mine workings can lead to formation of acid waters with pH 2.5–4.5.

REFERENCES

BUKOWSKI P., 1999 Carboniferous rock massif water storage capacity and its influence on the process of the coal mines self-flooding. PhD thesis . Arch. Główn. Inst. Górn., Katowice in Polish .

JANSON E., 2007 The impact of the pumped out waters from the liquidated coal mines on the the Przemsza River water quality. PhD thesis . Arch. Wydz. Górn. i Geoinż. AGH, Kraków in Polish .

KLECZKOWSKI A.S., WILK Z., 1968 The influence of the geological structure on the groundwater environment in the south-eastern part of the Upper Silesian Coal Basin. *Rocz. Pol. Tow. Geol.* **3** , 2/3: 83–202 in Polish .

KLECZKOWSKI A.S., WITCZAK S., 1967 Permeability and porosity of Carboniferous sandstones as related to depth (East Upper Silesian). *Bull. de l'Académie Polonaise des Sciences. Série de Sciences Géologiques et Géographique*, **1** , 1: 23 –31.

KOTAS A., 1985 Structural evolution of the Upper Silesia Coal Basin (Poland). X Congress Int. Strat. Geol. Carb. Compt. Rend., **3**: 459–469. Madrid.

PLUTA I., 2005 Mine waters of the Upper Silesian Coal Basin – origin, pollutants and purification. *Pr. Nauk. GIG*, : 169 in Polish .

ROGOŻ M., POSYŁEK E., 2000 Hydrogeological problems of the Polish coal mines. Wyd. GIG, Katowice in Polish .

RÓŻKOWSKI A., 1998 Origin of mine waters based on isotopic composition (Upper Silesian Coal Basin, Poland). Symp. on mine water and environmental impacts. Proc. IMWA, **1**: 53–68. Johannesburg.

RÓŻKOWSKI A., 2003 Upper Silesian Coal Basin. Geological and hydrogeological conditions. *In*: Hydrogeology of the Polish mineral deposits and mining water problems. **1**: Upper Silesian Coal Basin: 42–145. Wyd. Nauk.-Dyd. AGH, Kraków in Polish .

RÓŻKOWSKI A. (ed.), 2004 Hydrogeochemical environment of Carboniferous coal-bearing formations of the Upper Silesian Coal Basin. Wyd. U l., Katowice in Polish .

RÓŻKOWSKI A., RÓŻKOWSKI K., 2003 Hydrogeological environment of the Cracow Sandstone Series in the Upper Silesian Coal Basin. *In*: Współczesne problemy hydrogeologii, 11, 1: 177–193. Gdańsk in Polish .

RÓŻKOWSKI A., SOŁTYSIAK M., 2005 Proposition of the hydrochemical regionalization of the mining areas in the Upper Silesian Coal Basin. *In*: Współczesne problemy hydrogeologii, 12: 617–622 . Wyd. Uniw. Mikołaja Kopernika, Toruń in Polish .

RÓŻKOWSKI K., 2004 Groundwater chemistry of the coal-bearing Carboniferous – groundwater complex of the Cracow Sandstone Series. *In*: Hydrogeochemical environment of the Upper Carboniferous: 75–78. Wyd. U l., Katowice in Polish .

RÓŻKOWSKI K., WITKOWSKI A., 2004 Hydrogeological properties of the Upper Carboniferous groundwater complexes. *Ibidem*: 30–34.

TOTH J., 1995 Hydraulic continuity in large sedimentary basins. *Hydrogeol. J.*, **3**, 4: 4–16.

WAGNER J., 1998 Hydrogeological characteristics of the Upper Carboniferous in the main syncline of the Upper Silesian Coal Basin. *Biul. Państw. Inst. Geol.*, **3 3** : 55–96 in Polish .

WILK Z., 1965 Size, depth and water inflow into the coal mines in the eastern part of the Upper Silesian Coal Basin. Wyd. Geol., Warszawa in Polish .

WILK Z. (ed.), 2003 Hydrogeology of the Polish mineral deposits and water mining problems. AGH, Kraków in Polish .

WITKOWSKI A., 1982 Variety of the porosity, drainage capacity and permeability of the Upper Carboniferous rocks in the Pszczyna–Strumień region in Upper Silesian Coal Basin (based on the laboratory studies). PhD thesis . Arch. Kat. Hydrogeol. i Geol. Inż. U l., Katowice in Polish .