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title: **Geogenic and mining factors controlling the groundwater conditions of the Cracow Sandstone Series (CSS)**

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GEOLOGICAL CONDITIONS AND MINING ACTIVITY

The Cracow Sandstone Series (CSS) forms the upper lithostratigraphic series of the coal-bearing Carboniferous formation (Westphalian B, C, D) in the Upper Silesian Coal Basin (USCB). 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 (Kotas, 1985).

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 1500 km². The total thickness of the formation is variable, ranging from tens to 1140 m. The roof of a series lies on the depth changing from +320 to -720 m below sea level.

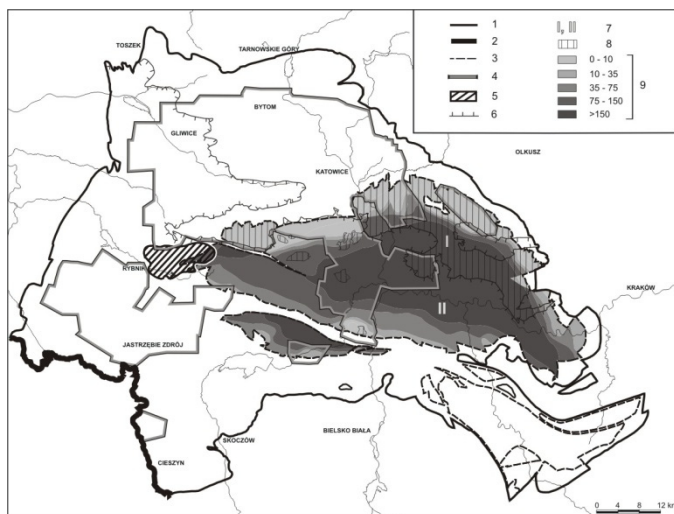


Figure 1. Hydrochemical map of the Cracow Sandstones Series (CSS). Explanations: 1 — Extension of the productive Carboniferous formation in the Polish part of the USCB; 2 — State border; 3 — Extension of the CSS; 4 — Extension of the coal mine mining areas; 5 — Salt deposit in the Miocene formation; 6 — Extension of the isolating series of the Miocene formation; 7 — Hydrogeological subregions; 8 — Recharge areas of the CSS aquifer; 9 — Mineralization (TDS) and hydrochemical types of groundwater in the sole part of the CSS: 0–10 (g/dm³), multi-ion types; 10–35 (g/dm³), multi-ion types; 35–75 (g/dm³), Cl–Na type; 75–150 (g/dm³), Cl–Na, Cl–Na–Ca types; >150 (g/dm³), Cl–Na, Cl–Na–Ca types.

An area of the CSS extent characterizes block tectonics. The north-eastern part of the CSS area lies in range of the Paleozoic block where the overlying formations are of the Mesozoic and Quaternary age. The southern and central parts are within the reach of the Carpathian Fordeep, where sediments are covered with the clayey formation of Miocene. 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. 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 190 to about 650 m. Due to the great number of mineable coal seams in the sequence, exploitation is carried out simultaneously at several depth levels. Localization of mining areas within the CSS extent is shown on Fig. 1.

Mines exploiting coal seams within the CSS characterize with total inflows in range from a few to 52.8 m³/min. Maximal individual inflow to the mines results from proximity of present and buried river valleys in the NE part of the USCB. A tendency of water inflow decreasing to specific mining levels with increasing depth was observed (Wilk, ed., 2003). The total inflow amount depends on morphological and 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 and flooded, the others only partly.

HYDROGEOLOGICAL ENVIRONMENT OF THE CRACOW SANDSTONE SERIES

The geological structure of the CSS is diversified. The Paleozoic block structure in the NE part of the USCB is treated as the main recharge area of the CSS hydraulic systems due to its 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 CSS, two hydrogeological subregions of different hydrogeological conditions have been distinguished: the north-eastern (I) and the south-western (II) (Fig. 1). Their boundaries are delineated by the extent of the isolating series of Miocene formation.

In a hydrogeological profile of the CSS hydrogeological complex prevail water-bearing sandstones and conglomerates of thickness attaining up to 24 m. Claystones and siltstones are reduced to a thin 0.05–6.2 m isolating intercalations. Results of field and laboratory research of the CSS sandstones and conglomerates hydrogeological properties examined in an interval up to 1200 m were recently presented in the paper of Rózkowski and Witkowski (2004).

Conducted studies revealed high variability of hydraulic conductivity from 5.0×10^{-8} m/s to 3.3×10^{-4} m/s. Laboratory investigations of sandstones permeability showed its falling tendency with increasing depth (Fig. 2). Effective porosity of coarse-grained clastic rocks reduces adequately to depth from 31.7 to 4.6%, while specific yield — from 10.0 to 1.6%.

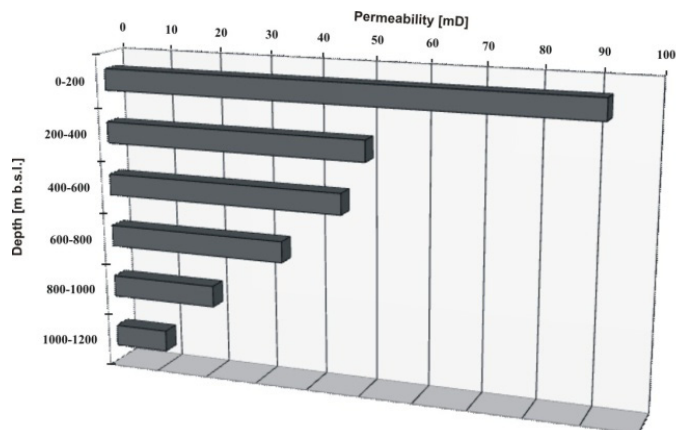


Figure 2. Variation of permeability of CSS water-bearing strata with depth in a division to 200 m intervals.

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 majority hydrogeological parameter values with grain diameter size; 4) 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 at the outcrop areas. As a result of the mining activity increases the transmissivity of rock massif as well as a storage capacity and permeability. Decrease of hydrogeological parameters of sandstones with depth is connected with progressing processes of deposits lithification. Water storage capacity of sandstones represented by specific discharge of wells varies with depth from 10.25 m³/h/1mS at the depth of about 60 m to 0.004 m³/h/1mS at the depth of 850 m.

According to Toth's theory (1995) it can be assumed, that in the extent of the whole Upper Silesian Carboniferous sedimentary basin, within which the CSS structure is located, groundwaters under the conditions of gravitational flow pattern, are in mutual hydraulic connection, independently from the 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 (Rózkowski, 2003).

Natural hydrogeological environment of the CSS has been transformed at the areas of mining activity influence (Rogoż, Posytek, 2000; Rózkowski, 2003; 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 connections 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. 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 AND GENESIS OF GROUNDWATERS

Total water mineralization within the CSS formation expressed as TDS varies between 0.12 and 179.15 g/dm³. There is observed a general trend of water total mineralization increase with depth as well as a change of ion mutual relations (Fig. 3). Analysis of hydrochemical investigations has shown an occurrence within the CSS hydrostructure of vertical, regional zonality, typical for sedimentary basins (Rózkowski, 2003). On the base of chemical composition and hydrochemical indices of groundwaters, were distinguished three hydrochemical zones in a vertical profile of the CSS, which are in correlation with the hydrodynamic zones (Rózkowski, 2004). In a relation to geological structure, hydrodynamic conditions and intensity of mining exploitation, vertical extent of hydrochemical zones differs in both subregions and even within their boundaries as well as varies in time.

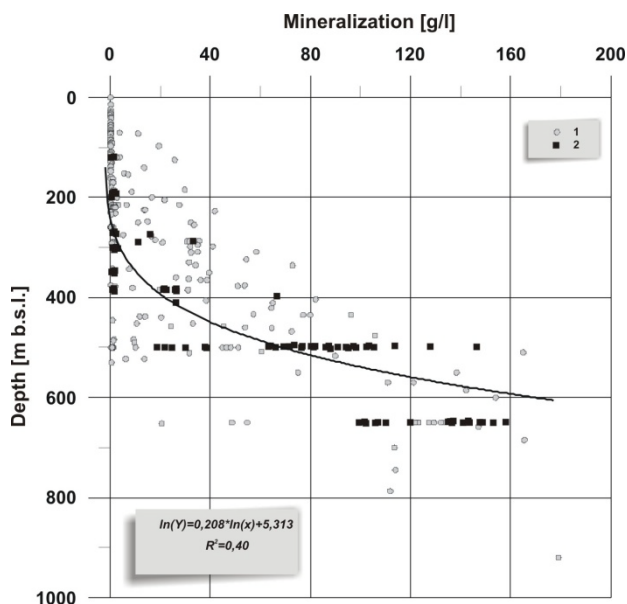


Figure 3. Increase of groundwater mineralization with depth in CSS hydrogeological complex. Explanations: 1 — waters sampled from bore-holes; 2 — waters sampled from mine galleries.

The results of isotope investigations confirmed occurrence of mentioned three hydrochemical zones in a hydrogeological profile of the CSS (A. Rózkowski, 2003). Zone of infiltration waters is characterized by isotope values: $\delta^{18}\text{O}$ -11.7 to -9.0 per mille and δD -80 to 67.9 per mille. Waters of this zone with mineralization from 0.5 to 3.6 g/dm³ occur in the first subregion at the depth interval from the roof of the series to 410 m. In a gaseous composition of water dominate atmospheric gases. Zone of mixed waters with a mineralization from a dozen or so to 62.7 g/dm³ characterize isotope values ranging from $\delta^{18}\text{O}$ -8.2 to -8.8 per mille and δD -67 to -61 per mille. Nitrogen is dominant in a gaseous composition of the upper part of their occurrence, while methane – at the lower one. Such results reveal presence of both oxidizing and reduction zones in hydrochemical profile. Relict waters occurring at the depth under 650 m have isotope values: $\delta^{18}\text{O}$ -6.30 to -3.80 and δD -49.0 to -36 per mille, while their mineralization varies from 79.9 to 149.8 g/dm³. Brines with TDS values exceeding 35 g/dm³ belong to hydrochemical types Cl-Na and Cl-Na-Ca. They occur only in a reduction zone. In a gaseous composition dominates 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. 1). 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: $\text{HCO}_3 \rightarrow \text{SO}_4 \rightarrow \text{Cl}$. 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 activity of coal mining.

Analysis of spatial distribution of mineralization zones has shown an occurrence of waters with mineralization from 0.3 to 10.0 g/dm³ 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 HCO₃ and SO₄ ions. In a zone of waters with TDS from 5 to 10 g/dm³, in an ionic water composition dominate chlorides and seldom sulfates. In the second hydrogeological subregion, in the 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 is a fundamental factor forming present hydrodynamic field of the CSS (Rózkowski, Rózkowski, 2003). 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. Desalinization of mine waters in time is in general a main result of the intensive drainage (Fig. 3). 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: $\delta^{18}\text{O}$ –11.18 to –3.80 per mille and δD –80 to –36.0 per mille. These data revealed that sampled mine waters belong to the group of contemporary infiltration waters, but also mixed and relict ones (Rózkowski, 2003). The investigations carried out in the mines 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 usually 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 500 m. Underneath brines typical for stagnant zone are present. In the second hydrochemical region mine waters are characterized by variable chemical composition 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 was investigated to the depth of 300–400 m. 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. Pumped waters chemical composition is strictly connected with exploitation technology, mine workings liquidation technique and especially with variations of groundwater level in abandoned workings. Hydrochemical processes in a rock mass under the mining drainage are connected mainly with oxidation of metal sulfides, especially of pyrite and marcasite. In a result of this processes increases the concentration of sulfates, selected metals, among them total iron, water hardness, suspension level, while simultaneously decreases the pH of water. In favorable hydrogeochemical environment, oxidation of sulfide minerals in mine workings can lead locally to formation of acid waters with pH 2.5–4.5.

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