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# IMPACT OF MINING ON THE GROUNDWATER CHEMISTRY IN THE UPPER SILESIAN COAL BASIN (POLAND)

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## ABSTRACT

The Upper Silesian Coal Basin (USCB), 7500 sq.km area (including 5500 sq.km in Poland), is situated in the Variscian Upper Silesian intermountain depression. Coal - bearing Upper Carboniferous rocks occur beneath the permeable Mesozoic and Quarternary sediments in the NE part of the USCB and the impermeable Tertiary clay series in the southern and north - western parts. Studies on hydrogeochemical environment showed a normal vertical and horizontal hydrogeochemical zone in the full extent of the basin. This zone is characterized by changes in mineralization and chemical of waters along circulation routes. Strongly mineralized waters of isolated structures represent brines of the type Cl-Na and specially Cl-Na-Ca. A general trend of increased mineralization is noted along with depth of occurrence of water independently of age of the strata. The general regularity is disturbed by the phenomena of hydrochemical inversion mainly due to the mining activity.

In the USCB coal deposits have began to be intensively exploited as early as the 18th century. The coal seams are exploited by the underground mining method, mainly by the longwall system, down to the average depth from 650 m to 1200 m. The steadily increasing mining depth and the opening of new mining levels increase the extent of drainage by mines and amounts as well as salinity of pumped out water. The total quantity of water pumped out of mines equals 724 $m^3$/min. Area of decreased piezometric heads, because of the mine drainage, covers about 2000 sq.km. As the coal mine workings are carried out in different hydrochemical zones, the chemistry of the pumped mine waters vary significantly. with the mineralization of natural mine water ranging from 0.2 to 372.0 g/$dm^3$.

The artificial hydraulic interconnections created by mining activities and deep drainage cause changes in the natural hydrochemical regime of groundwater. The desalination

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effect caused by mining activity depends mainly on the depth and size of mining, duration of exploitation, drainage activity and geological conditions of the USCB. The present hydrochemical zone in the USCB determined by the mining impact is shown on the maps of groundwater mineralization at the depth of 500 and 750 m, as well as on the map of the depth of the occurrence of saline waters (35 g/dm$^3$). There is a close correlation between mineralization of water in the Carboniferous within the coal fields and the type of overlying rocks as well as degree in which the rock mass is affected by mine workings. The maximum salinity of water was found in depressional structures under the cover of sealing. Tertiary rocks, host structure not covered by the Tertiary and affected by mine workings for over a hundred years are characterized by a marked desalination of waters to the depth of about 500 m.

## INTRODUCTION

The Upper Silesian Coal Basin (USCB) is located in the southern Poland. Considering the resources and output of hard coal about 150 Mt/y the USCB is at present one of the biggest coal basins in the world. It has been mining since the second half of the eighteenth century. The average depth of mining is about 650 m, while the maximum depth is 1200 m. The coalfield area covers about 2000 sq.km (Figure 1). The majority

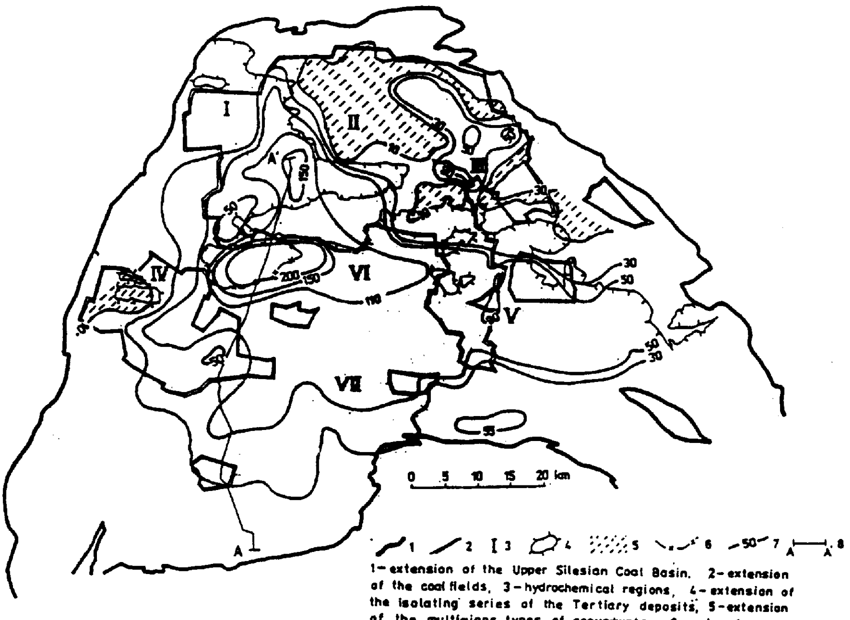


Figure 1. Sketch-map of the groundwater mineralization (USCB) on the depth 250 m u.s.l.

of coal mines is disposed in the area of shallow occurring of productive Carboniferous. The area of coal deposits occurring deeper and overlaid by the clayey Tertiary rocks is now under intensive mining development. The artificial hydraulic interconnections

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treated by mine activities and deep drainage cause changes in the natural hydrochemical zones of groundwaters.

## GENERAL HYDROGEOLOGICAL CHARACTERISTICS OF THE USCB

The Upper Silesian Coal Basin (USCB), 7500 sq.km in area (including 5500 sq.km within Poland), is situated in the Upper Silesian variscitic intermountain depression (Kotas, 1985). Coal-bearing Carboniferous rocks occur beneath the Quaternary and Mesozoic formations in the NE part of the basin and clay Tertiary series both in its southern and western-parts Within the Tertiary formation the salt deposits occur locally (Figure 1).The results of the hydrogeological investigations which have been carried out in the USCB have been published presently in the papers: Rogoz, Rozkowski, Wilk, 1987; Rozkowski, 1987 and the others.

Three water-bearing formations have been identified in the hydrogeological section of the USCB: Quaternary, Mesozoic and Carboniferous. Clay Tertiary sediments form an aquiclude. The Upper Carboniferous formation is represented by a clay-silt-sandstone complex with coal seams. As far as the lithology and water-bearing conditions are concerned two sandstone series as well as two siltstone-claystone series can be distinguished in the vertical section of those deposits. There are: Cracow Sandstone Series (Westphalian B-D), Upper Silesia Sandstone Series (Namurian B-C), Siltstone Series (Westphalian A, lower Westphalian B) and Paralic Series (Namurian A). Carboniferous aquifers represented by sandstones, partly siltstones, have the thickness ranging from 0.5 to more as several dozen meters. They are isolated from each other by intercalations of impermeable claystones except for areas of mining, fault zones and zones of sedimentary wedging outs where hydraulic connections are traced.

Hydrogeological properties of Carboniferous sandstones have been investigated by: Bromek, 1977; Kleczkowski et.al., 1976; Kleczkowski, Witczak, 1967; Rozkowski, Witkowski, 1988; Witkowski, 1987 and others. Effective porosity of sandstones varies between 0.5% and 31% while their specific yield ranges from 0.1 to about 23%. According to laboratory examination permeability of Carboniferous sandstones varies in a very wide range from 0.005 to 1400 m/d. Hydraulic conductivity tested in the boreholes varies from $4.0 \times 10^{-11}$ m/s to $5.0 \times 10^{-4}$ m/s.

According to Witkowski (1987) the decisive influence of the variability of the hydrogeological properties of sandstones and Carboniferous mudstones is exerted by the differentiation of the total volume of the open pores and their size. This differentiation is the result of broadly understood digenetic processes, first of all, of sediments compaction and recrystallization processes as well as weathering ones. The second essential factor deciding on the differentiation of the hydrogeological properties is the con- tent of the smallest fraction of grains in the considered rocks. The third factor playing a certain role, though still not well examined, is the kind of matrix. The reflection of the influence of these processes is the variability of the discussed properties in the lithostratygraphic profiles of the Carboniferous formation. Distinct tendency of decreasing of all physical properties of sandstones with the depth can be observed when analysing laboratory results from the boreholes to the depth 2000 m (Rozkowski and Witkowski, 1988). That is particularly observable in the lower intervals of the Upper Carboniferous formation. Sandstones below the depth 900-1000 m are characterized by slight effective porosity not exceeding 10%, low specific yield below 6.0% and very slight permeability lower than 0.2 m/d. It means that Carboniferous sand- stones occurring below 900-1000 m are practically impermeable.

In the NE part of the basin rocks of the Carboniferous formation out crop or are overlain by permeable Mesozoic, mainly triassic dolomites, and Quaternary sands. In the southern and western parts the formation is overlain by impervious Tertiary clays (Figure 1). Carboniferous aquifers are recharged in zones of outcrops or through

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permeable cover rocks in the N and NE parts of the USCB. The recharge by water-bearing Quaternary sands of recent and buried valleys has the major importance. Yield of Carboniferous aquifers suddenly decreases when they are covered by impermeable Tertiary formation.

Taking into account the recharge conditions of the Carboniferous aquifers 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).

Drainage of rocks by sand pits, ore and coal mining workings effects in disturbances of natural hydrogeological conditions in the USCB (Rogoz, Staszewski, Wilk, 1987; Rozkowski, 1989; Wilk, 1980). It appears in diminishing or even decline of surface outflow, changes of pressures and quality of groundwaters, direction and velocity of flow, decline of springs, loss of water in wells, diminishing of productive value of fields and forests. Aquifers of the productive Carboniferous under natural conditions were drained by river valleys in the first region (I) and along fault zones in the second hydrogeological region (II). At present the discharge of the aquifers appears mainly as a result of mining drainage.

Pumping in the USCB about 724 $m^3$/min by coal mines caused drainage of the Carboniferous aquifers. Triassic and Quaternary rocks are drained too but to a smaller extent and almost only in the first hydrogeological region. Area of decreased piezometric pressu- res covers about 1720 sq. km. High index of underground run-off ranging mainly from 7 to 11 l/s/sq.km in the first hydrogeological region is a measure of mining drainage intensity and infiltration rate. Underground run-off in this region can be even locally almost balanced with total recharge by precipitation.

## HYDROCHEMISTRY

Groundwaters occurring within the UCSD appear differentiated in chemical composition and total mineralization (Rozkowski, Przewlocki, 1987; Rozkowski, 1987). Fresh waters occur in the covering Quaternary, Jurassic and Triassic formations as well as in the outcrop areas of the Carboniferous formation. Groundwaters in the Tertiary formation are characterized by TDS ranging from 0.5 to 220 g/$dm^3$. Two hydrochemical provinces, which determine the chemical composition of the waters, occur within the Tertiary. In the area of occurrence of the Tertiary gypsum and salt sediments, water of the $SO_2$ type with varying cation content occurs as well as water of the Cl-Na type with high $SO_4^{2-}$ content. Outside this area water is of the Cl-Na type. Methane predominates among gases of those groundwaters.

The low mineralizated (below 1.0 g/$dm^3$) groundwaters, occurring in the Jurassic and Triassic deposits, are mostly of the $HCO_3$-Ca and $HCO_3$-Ca-Mg types.

In the coal-bearing Carboniferous formation TDS of groundwaters ranges from 0.5 to 372 g/$dm^3$. Low mineralized waters of the chemical types: $HCO_3$-$SO_4$-Ca-Mg, $HCO_3$-Na and Cl-Na predominate in the zone of exchange and mixing of groundwaters with atmospheric waters. Highly mineralized waters of isolated poor permeable-structures represent brines of the Cl-Na and Cl-Na-Ca types. Methane from degasation of coal seams predominates in gaseous composition of those brines. There is also recorded increased radioactivity of brines.

Mine waters are highly varying in their chemical composition. mineralisation of natural mine water ranges from 0.2 to 372g/$dm^3$ but the cumulative pumped out waters mineralisation is up to 110 g/$dm^3$ (Rozkowski, 1987). Waters with total mineralization up to 1.5 g/$dm^3$ are multi-ions and are pumped out in quantities of the order of 275 $m^3$/min. Those are from mines located in the first hydrogeological region as well as

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from the areas of "hydrogeological windows" situated in the second region. waters with mineralization over 1.5 $g/dm^3$ are pumped out of mines in quantities of the order of 449 $m^3/min$. Waters with mineralization up to a few g per $dm^3$ belong to the hydrochemical types $HCO_3$-Cl-Na, HCO3-SO4-Na and Cl-$SO_4$-Na. Water with increased mineralization is usually of the Cl-Na type and strongly mineralized brines represent the hydrochemical type Cl-Na-Ca.

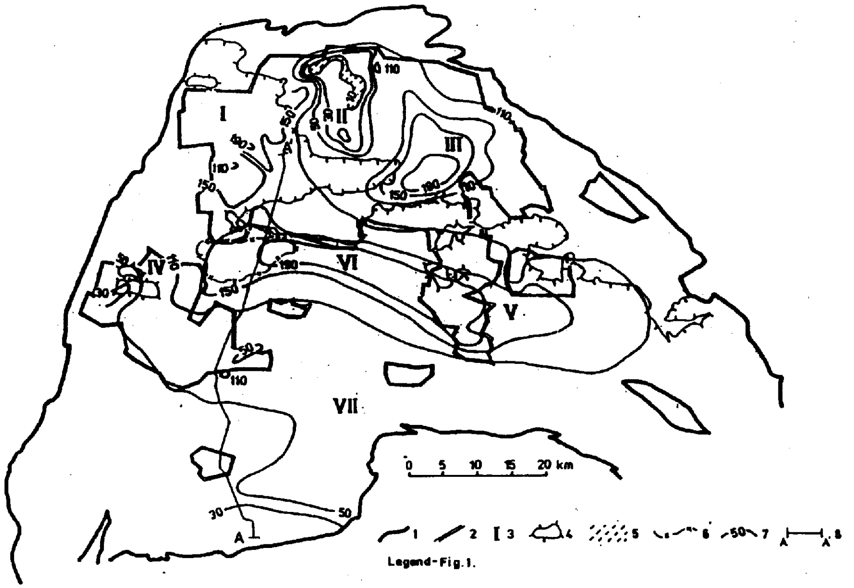


Figure 2. Sketch-map of the groundwater mineralization (USCB) on the depth 500m u.s.l.

Studies on hydrogeochemical environment demonstrate a normal hydrochemical zonality within the extent of the USCB (Palys, 1971; Rozkowski, Rudzinska, 1983; Rozkowski, Gajowiec, Wagner, 1989,1991). There has been found a general trend of increasing groundwaters mineralization with depth independently on the age of rocks. This general trend can be disturbed by anomalies of the geogenic and anthropogenic origin.

The formation of hydrochemical zones is different in the northern (I) and the southern (II) hydrogeological regions. This is the result of differences in permeability of the deposits over- lying the Carboniferous as well as to the variable recharge and drainage conditions of the water - bearing horizons (Rozkowski, Rudzinska, 1983). In the first (I) hydrogeological region the zone of the low mineralized waters includes permeable sediments of the Quarternary, Jurassic, Triassic and the upper most part of the Carboniferous, until the depth 400-600 m below the surface (Figure 3).

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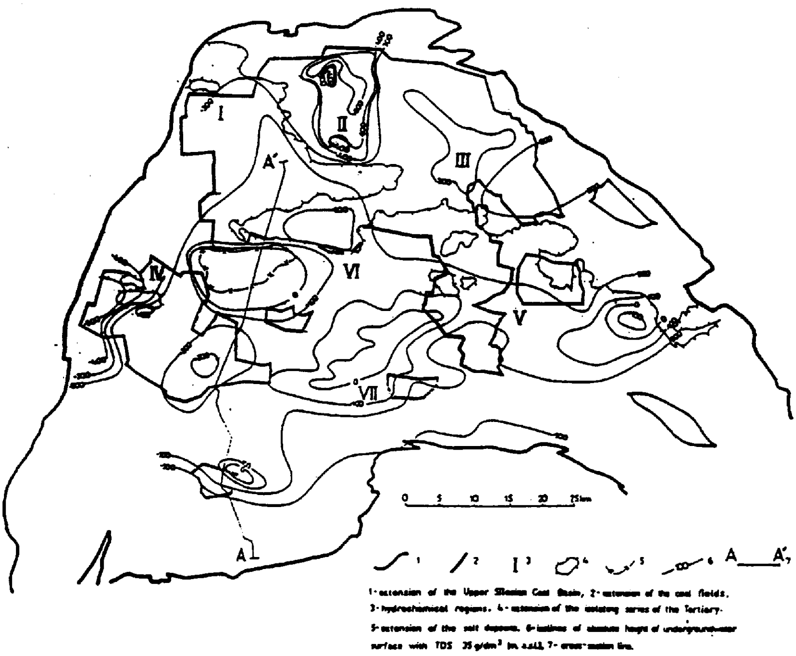


Figure 3. Sketch-map of the surface of brines (USCB) with TDS 35g/dm$^3$

In the second (II) hydrogeological region which is mantled with the clayey Tertiary deposits fresh water occurs in the Quarternary only. The hydrochemical zone within the Tertiary formation is marked by multi-ion saline waters and brines, while in the Carboniferous Cl-Na and Cl-Na-Ca brines are found usually.

Hydrochemical investigations carried out by the authors (Chmura, Gajowiec, Wagner, Rozkowski, 1991) have shown that the depth of brines occurring in the USCB is variable (Figures 3 and 4). This is connected with variability of geological conditions and mining activity within the separate geological structures of the USCB .

The variety of hydrochemical zones within the USCB has been analized based on the population of 1233 chemical analyses of groundwaters. The samples of these groundwaters have been collected from boreholes but above all from mine workings. Taking into account the results of this analysis seven hydrochemical regions have been distinguished within the Carboniferous formation of the USCB (Rozkowski, Chnmura, Gajowiec, Wagner, 1989, 1991). In those regions hydrogeochemical gradients vary in the great extent (Table 1). The position of the regions is shown on the Figures 1 to 3.

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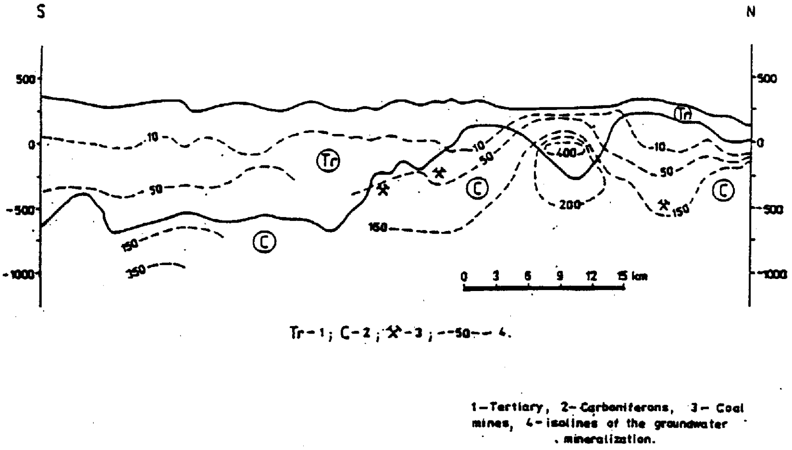


Figure 4. Hydrochemical cross-section (1) Tertiary (2) Carboniferrous (3) Coal Mines and (4) Isolines of ground water mineralisation

The first region situated within the Gliwice folds. The second one includes the western part of the Bytom syncline and the main anticline of the USCB, where mining reaches up to about 1000m The third region covers the eastern part of the mentioned structures where mining reaches only up to about 500 meters. The Jejkowice and Chwalowice synklies are in the fourth region. The fifth, sixth and seventh regions are situated within the main synclince of the USCB. Within this structure there are analysed separately: the area of the Tertiary graben Zawada which includes the salt deposit (the sixth region) and the foredeep of the Carpathian Mountains ss. (the seventh region). The remaining part of the main syncline constitutes the fifth region.

Increase of groundwater mineralization with depth in the separate hydrochemical regions has been estimated by calculation of regression function of mineralization as amount of TDS versus depth (Rozkowski, Gajowiec, Wagner, 1989). Changes of chemical composition of waters have been estimated on the base of hydrochemical maps (Figures 1-3) and cross-section (Figure 4) and above all on tabulated chemical analysis of waters. Calculation of regression function has enabled us to trace tendency of water mineralization changes with depth under natural environmental conditions. Calculation of hydrogeochemical gradients has been done using the latest data under natural and changed by mining activity conditions (Table 1). Hydrochemical differentiation of distinguished regions (I-VII) within intervals of depth 0-500 and 500-1000 meters shows in Table 1.

## FACTORS FORMING THE HYDROCHEMICAL ZONES WITHIN THE USCB

Differentiation of the present hydrochemical zones within the USCB in the interval of depth to 1200 m under surface (u.s), depends on two fundamental factors, i.e.: geological conditions and theextent of mine workings. The Triassic ore deposits underground mining, quarries activity and rocks drainage by wells play marginal role in this process. Taking into consideration the geological factor the essential importance of

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isolating role of the clayey Tertiary formation is emphasised. This formation creates the main hydrochemical barrier in the hydrogeological section of the USCB.

Table 1. Characteristics of hydrochemical regions (after Rozkowski, Chmura, Gajowiec, Wagner, 1990).

| Regions | Intervals depth of | Mineralization groundwaters $g/dm^3$ | Main hydrochemical types of waters | Hydrogeochemical gradient $g/dm^3 \times 100/m$ |
|---|---|---|---|---|
| I | 0 - 500 | 0.3 - 80 | HC03-Ca, $HCO_3$-$SO_4$Ca -Mg Cl-$SO_4$-Na, Cl - Na | 6$^x$ |
| | 500-1000 | 1.7 - 329 | Cl-Na, C1-Ja-Ca | 40$^x$(60)$^{xx}$ |
| II | 0- 500 | 0.3 - 23 | $HCO_3$-Ca, $HCO_3$-$SO_4$Ca -Mg Cl-$SO_4$-Na | 2$^x$(4)$^{xx}$ |
| | 500 - 1000 | | Cl - Na | 15$^x$(40)$^{xx}$ |
| III | 1- 500 | 0.3 - 50 | $HCO_3$-Ca, Cl -$SO_4$-Ca-Mg , Cl -Na | 2$^x$(22)$^{xx}$ |
| | 500-1000 | 1.0 - 250 | C1-Na, C1-la-Ca | 40$^x$(50)$^{xx}$ |
| IV | 0- 500 | 0. 4 - 28 | $HCO_3$-Ca, $HCO_3$-$SO_4$-Ca -Mg , Cl-$SO_4$-Na, C1-Na | 2$^x$(5)$^{xx}$ |
| | 500-1000 | 2.8 - 120 | C1-Na, C1-Na-Ca | 22$^x$(22)$^{xx}$ |
| V | 0- 500 | 0. 5 - 100 | $HCO_3$-Ca-Mg, $HCO_3$-$SO_4$-Ca-Mg, Cl-Na | 8$^x$ |
| | 500 - 1000 | 14.0 - 202 | C1-Na, Cl-N a-Ca | 23$^x$(50)$^{xx}$ |
| VI | 0 - 500 | 0.3 - 400 | $HCO_3$-Ca, $HCO_3$-$SO_4$-Ca-Mg Cl -Na | 80$^x$ |
| | 50 - 700 | 5.5 - 351 | Cl-Na, C1-Na-Ca | 130$^x$ |
| VII | 0 - 500 | 0.5 - 79 | $HCO_3$-Ca, $HCO_3$-C1-Na, Cl-Na | 5$^x$ |
| | 500-1000 | 2.5 - 150 | Cl-Na, C1-Na-Ca | 20$^x$(30)$^{xx}$ |

x - mine waters
xx - nattural environment

The Tertiary gypsum and salt deposits in the north-western part of the basin also play an important role in formation of mineralization and chemical composition of groundwaters. It refers mainly to Miocenic salt bearing deposits situated in the Zawada graben in the western part of USCB. They have the great influence on chemical composition of groundwaters in the Tertiary and Carboniferous formations in the vicinity to deposits (Figures 1 to 4). The saline deposits are situated at the interval of depth from 110 to 349 m u.s. Its influence manifests itself in anomaly brine

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mineralization increase (TDS from 200 to 350 g/dm$^3$) in both: horizontal and vertical directions (Figure 4). The salt deposits are surrounded by the aureole of highly concentrated brines. TDS of these brines decreases in response to growing distance from the salt deposits (Figure 4). The range of salt deposits influence on brines composition in the Tertiary and Carboniferous formations reaches about 20sq.km. The block-tectonics is very distinctly developed within the USCB. It plays an important role in the creation of hydrodynamic and hydrochemic barriers. The regional fault zone which enclosed the seventh (VII) hydrochemical region from the north is the good example of such a barrier.

The zones of some hydrochemical anomalies distinct by higher mineralization of groundwater correspond with the trend of large regional faults. Some large-scale hydrochemical anomalies probably can be connected with the paleohydrogeological development of the USCB (Palys, 1967; Oszczypko, 1981 and others).

The second fundamental factor modifying natural mineralization and chemical composition of groundwater, in the USCB is the mining activity. Slides cracks and destressing of rocks accompany mining excavation. These processes cause increase of rocks permeability and hydraulic connection of water from different aquifers in effect of interruption of isolating layers. Size of mining drainage is determined by geological structure, duration and depth of underground hard coal exploitation.

The amount of underground water pumped out by coal mines (724 m$^3$/min) is the main reason of disturbance of hydrochemical regime in the USCB. The longlasting and deeply ranging drainage activity of coal mines causes decreasing of natural drainage basement. Deep penetration of low mineralized waters (TDS below 10 g/dm$^3$) from overlying, aquifers as well as technological mine water gradually desalinates brines.

Forming of groundwaters chemical composition undergoes continually during mine exploitation. The forgoing, phenomenon, enlarged by existence of permeable overburden, formed the low-mineralized waters in the NE part of the USCB (Figures 1 to 3). There are local ground water intakes, in the mentioned part of the USCB, exploiting low mineralized waters from mine excavations situated on levels even more than 600 m below sea level. The development of the new deeper mine levels in the Paralic series of the Productive Carboniferous is connected with the inflow of highly concentrated brines.

Desalination of brines, caused by coal mine drainage, has been observed in the second hydrogeological region (II) of the USCB as well. This phenomenon is connected with the active drainage effect of less mineralized waters from the Tertiary formulation and from the upper links of the Carboniferous too. The groundwater flow from the areas of the hydrogeological windows under the influence of mining drainage has been taken into account by Rozkowski, 1985.

## CONCLUSIONS

Studies on hydroyeochemical environment of the USCB carried out by the authors have shown a normal vertical and horizontal hydrochemical zonality in the extent of the basin. The general natural regularity of it is disturbed by the refreshing effect caused by mining activity. The refreshing effect depends on the depth and size of mining, duration of exploitation, drainage activity and geological conditions of the area.

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