Hydrogeology of Deep Carboniferous Coal Deposits within the Upper Silesian Coal Basin (Poland)

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ABSTRACT

Hydrogeological investigations of the deep Carboniferous aquifers within the main syncline of the Upper Silesian Coal Basin (Poland) have been presented in the paper. Investigations have been carried out in the boreholes to the depth 2200 m.

Hydraulic conductivity of investigated aquifers ranges from 4.54×10^{-9} up to 2.27×10^{-7} m/s, while the specific yield from 0.1 to 23% and specific capacity varies from 4.5×10^{-3} to 3.0×10^{-4} cubic meter per hour. The general trend of diminishing of these parameters values with the depth can be observed.

Groundwater mineralization increases with the depth up to above 250 g/dm^3. The hydrostatic conditions are typical for the Carboniferous aquifers to 1000 m. The lower aquifers to 1600 m are characterized by an overpressure.

The inflows to the deep mines will be connected with the drainage of the relict brines.

INTRODUCTION

Considering the resources and output of hard coal (180 mln T/y) the USCB is at present one of the biggest coal basin in the world. It has been mined since the second half of the 18th century. The average depth of mining is about 650 m. The coal deposits are found in the Upper Carboniferous formation. Extraction has taken place mainly in the northern sector of the basin. Because of the extraction of the shallow coal deposits in these sector, the southern part of the basin it means the area of the main syncline of the USCB is only prospective for mining. Carboniferous deposits appear there under the thick overburden of the Tertiary strata. The coal deposits within the main syncline have been prospected in some places and during the last a dozen or so years several new mines have been built (Fig. 1). Unfortunately hydrogeology of Carboniferous formation has been recognized only to the depth about 800 m. The future mining will take place to the depth 1200 m or even 1500 m.

Before designing new mines or redeveloping existing mines it is essential to possess the adequate knowledge of hydrogeology of deep Carboniferous aquifers. The aim of investigation is to evolve a hydrogeological model of the deposits, and to provide data to determine chemistry of water as well as the sources, magnitude and zones of occurrence of possible inflows to the projected mines. Such investigations have been carried out in the last ten years in the boreholes to the depth about 2200 m. Preliminary results of the investigations are presented in this paper.

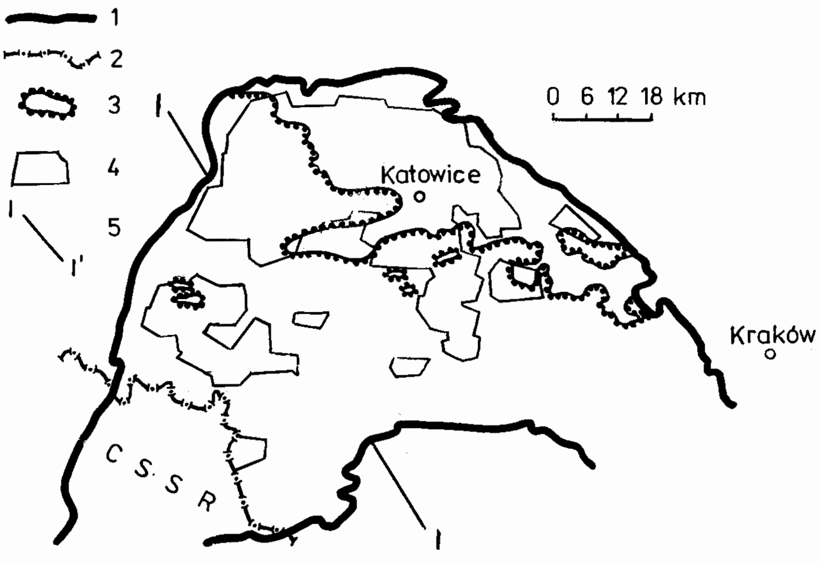

Fig. 1 Upper Silesian Coal Basin

1 - extension of the Upper Silesian Coal Basin, 2 - state boundary, 3 - extension of the isolating series of the Tertiary deposits, 4 - mine areas, 5 - cross section line

OUTLINE OF GEOLOGIC STRUCTURE

The USCB, the area of 7500 sq. km (including 5500 sq. km that belong to Poland), is situated within the Upper Silesian variscitic intermontana depression (Fig. 1). The geological development of which has been effected by the Variscian and Alpine orogenesis.

The Upper Silesian depression is filled with molassic sediments of the Upper Carboniferous system which thickness exceeds 7000 m in its central part. The productive Upper Carboniferous includes sandstones, conglomerates, claystones and siltstones as well as coal beds. As far as the lithology is concerned, two sandstone series and two siltstone - claystone series can be distinguished in vertical profile of those deposits. They are: Cracow Sandstone Series (Westphalian B-D), Upper Silesian Sandstone Series (Namurian B-C) Siltstone Series (Westphalian A, Lower Westphalian B) and Paralic Series (Namurian A).

Coal-bearing Upper Carboniferous rocks occur beneath the Mesozoic or Quarternary deposits in the NE part of the basin, and clay Tertiary series in the southern and western parts (Fig. 1). Tertiary strata, which attain up to 1000 m in thickness in Alpine depressional structures (Fig. 2), are at the bottom well permeable and have high water-bearing capacity.

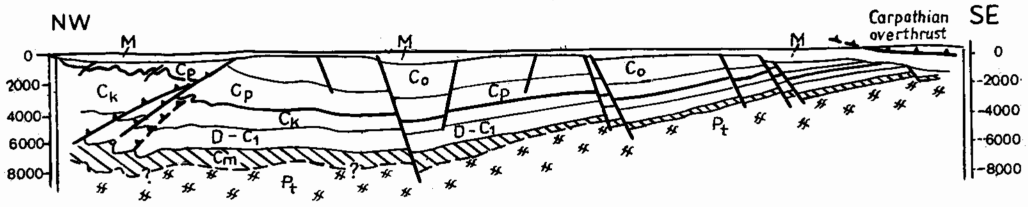

Fig.2 Cross-sections of the Upper Silesian Coal Basin

Pt - crystalline basement, Cm - Lower Cambrian, D-C1 Devonian-Lower Carboniferous carbonatic formations, Ck - clastig kulm sediments (Upper Visean-lowermost part of Namurian A), Cp-coal-bearing paramolasse (Namurian A), Co - coal-bearing orthomolasse (Namurian B-C - Westphalien D), M - Miocen

GENERAL HYDROGEOLOGICAL CHARACTERISTICS

Carboniferous aquifers within the USCB are isolated from each other by intercalations of impervious claystones. Aquifers are recharged in zones of outcrops or through permeable cover rocks. The Tertiary clay deposits isolate the underlying Carboniferous aquifers from atmospheric waters (Fig. 1, 2).

Aquifers of the productive Carboniferous have been drained by river valleys and zones of tectonic dislocations under natural conditions, undisturbed by human activity. At present we often note the drainage due to the mining.

Studies on hydrogeochemical environment have shown in the USCB a normal vertical and horizontal hydrogeochemical zonality in the extent of the basin. This zonality is characterized by changes in mineralization from 0.2 to above 250 g/dm^3 and chemical composition of waters along circulation routes. There is noted a general trend to increase mineralization along with depth of occurrence of groundwaters, independently of the age of the strata. This general regularity is disturbed by the phenomena of hydrochemical inversion.

METHODS OF HYDROGEOLOGICAL INVESTIGATIONS

Hydrogeological investigations of the coal deposits are accompanied by the geologic exploration of the deposits (2). The investigations have been carried out in the rotary drilled prospect holes. Such holes have to 2200 m in depth and are hardly suitable for the test pumping therefore bailing methods and "Halliburton" tubular tester have mainly been used there.

The application of drilling geophysics methods has proved they are very helpful in determination of the deep aquifers. To identify and record the hydrogeology of the coal deposits, the investigations of prospect-holes is accompanied by laboratory testing. The latter is performed in order to determine hydrogeologic properties of the rocks and the hydrogeochemical environment of the deposit together with its overburden. The hydrogeologic properties are tested on core samples, mainly at field laboratories. The testing program includes the determination of effective porosity, permeability and specific yield of the sandstones. Effective porosity and permeability are determined by means of pressurized, mercury-operated porosity meter and by vacuum method, respectively, whereas specific yield is tested by means of centrifuge. A comparative analysis of the determination of hydraulic conductivity by means of test pumping and laboratory testing has shown very high correlation in the case for deep Carboniferous aquifers.

Geochemical investigations include the determination of the environmental alkalinity (pH) and ion concentration in the ionic-salt complex of sandstones on the basis of the water extracts. This method enables to evaluate the depth of occurence of saline waters and to carry out a preliminary estimation of the hydrochemical environment of the coal deposits.

Chemical examinations of waters from the sampled aquifers are performed at stationary laboratories. The prospect boreholes serve for additional determinations of isotopic composition of groundwaters (T, ^{14}C, stable isotopes) in order to find their age and origin, as well as their position in the flow system.

FILTRATION AND STORAGE PROPERTIES OF CARBONIFEROUS SANDSTONES

Differentiation of granulometric and mineral composition and also observed different degree of diagenesis of Carboniferous sandstones causes changes of their effective porosity, specific yield and permeability.

Effective porosity of the examined sandstones varies between 0.5% up to 28.8%, while their specific yield is in the range from 0.1% to about 23%. The received values of the specific yield have been obtained in conditions of total gravitation drainage. According to laboratory examination permeability of Carboniferous sandstones varies in a very wide range from 0.002 mD to 750 mD. When converting received value of the permeability coefficient into the hydraulic conductivity of water at the temperature 10°C we obtain the following values $k_{min} = 1.5\times10^{-11}$ m/s and $k_{max}=5.6\times10^{-6}$ m/s. It means that these are the rocks practically unpermeable or slightly permeable.

Certain rules can be observed when analysing the obtained results according to the lithostratigraphic series. The sandstones belonging to the Cracow sandstone series and the mudstone series are characterized by the highest porosity, specific yield and permeability and also the largest variability. The sandstones belonging to the other two older series are generally characterized by lower values of the discussed hydrogeological parameters and their slighter differentiation (4, 5).

Distinct tendency to decrease both effective porosity and specific yield as well as permeability with the depth can be observed when analysing laboratory results from many drill-holes (the depth below 2000 m). It was determined that the sandstones position in the stratigraphic profile, that means stratigraphic depth and not the real depth measured from the roof of the formation, has the strongest influence on vertical variability of hydrogeological parameters (5). It is proved by differentiation of mean values of effective porosity and permeability of particular lithostratigraphic series (Table 1).

Table 1. Mean values of hydrogeological properties of sandstones of particular lithostratigraphic series.

parameters \ series		Cracow sandstone	mudstone	Upper Silesian sandstone	paralic
Effective porosity (%)		15.58	9.08	5.53	4.98
Hydraulic conductivity (m/s)	a:	2.0×10^{-7}	8.8×10^{-8}	1.3×10^{-9}	1.0×10^{-9}
	b:	2.2×10^{-7}	5.7×10^{-8}	4.5×10^{-9}	

a - laboratory tests b - field tests

It must be also noted that the mean values of hydraulic conductivity obtained by field tests are similar to the results of the laboratory tests.

Wider analysis of variability of each hydrogeological parameter at the depth range 700-1500 m below the surface has been carried out due to particular interest in deeper Carboniferous levels. Because of the geological conditions of the main syncline and great differentiation of the Carboniferous roof relief, depth ranges, where particular lithostratigraphic series appear, are varried but they often interfere with each other. Therefore the analysis of changes of mean values of the examined parameters have been carried out in general without taking their stratigraphy into consideration. 200 meters depth intervals were distinguished. The mean values of effective porosity, specific yield and permeability were calculated in the intervals (Table 2, Fig. 3).

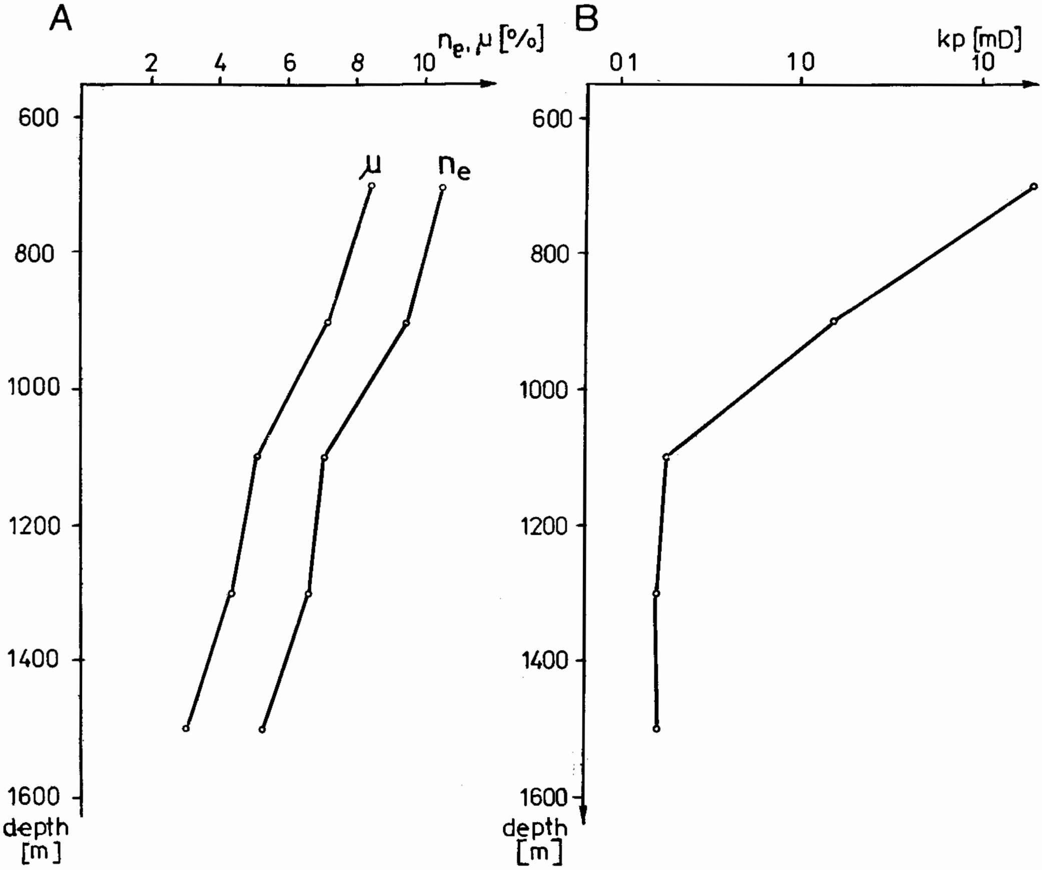

Fig.3 Changes of mean values of hydrogeological parameters of sandstones with the depth

Data analysis presented in table 2 proves consequent decrease of the values of the particular hydrogeological parameters with the depth (Fig. 3). This decrease is particularly observable in lower intervals. Below 1000 m this tendency is rather small and certain stabilization of mean values of the examined parameters can be observed. Generally we

Table 2. Mean values of hydrogeological properties of sandstones within 200 m depth intervals.

Parameter	Depth intervals begining from the surface (m)				
	600-800	800-1000	1000-1200	1200-1400	1400-1600
Effective porosity (%)	10.51	9.52	7.13	6.69	5.33
Specific yield (%)	8.43	7.22	5.10	4.39	3.06
Permeability (mD)	18.94	1.55	0.17	0.16	0.16

can state that sandstones below 1000 m are characterized by slight effective porosity not exceeding 10%, low specific yield below 5% and very slight permeability lower than 0.2 mD. Carboniferous sandstones occuring below 1000 m are practically unpermeable.

The lack of determination of storage coefficient is a real deficiency of researches into storage properties of deep Carboniferous aquifers. The value of this coefficient can be approximately determined using the results of researches in the field (1) and the nomograms drawn by T. Bromek. In case of sandstones belonging to Cracow sandstone series values should be in the limits $1.3-1.7 \times 10^{-5}$ and in mudstone series 6.1×10^{-6}. The average values of the coefficient for the Upper Silesian sandstone series and the paralic series should be about 4.5×10^{-6}.

Basing on the carried out investigations a large correlation between effective porosity and specific yield has been observed. The samples of sandstones and also mudstones taken from the very deep layers and characterized by low effective porosity about 1-4% were thorougly analysed. The samples were examined using total gravitation drainage. As it comes from the results of the research Carboniferous sandstones and mudstones, despite the low effective porosity, undergo the process of draining. Minimal drainage has been observed even at the rocks which effective porosity is about 1%. It supports the idea that the drainage is influenced not only by the size of pores. Low effective porosity may be caused both by the small diameters of pores and by their small number even when the diameters are large, which is proved by the researches into pore size distribution of the examined rocks.

The observed interdependences occure not only between specific yield and effective porosity but also between permeability and the above mentioned parameters. However these relations are not so intensive and they can be described with the exponential functions.

WATER BEARING CAPACITY AND THE HYDRODYNAMIC PRESSURES

Water bearing capacity of the deep Carboniferous aquifers is very low and it is decreasing with the depth from 0.03 to 0.00001 cubic meter per hour. Representative values for the depth interval 700-1000 m are about 10^{-3} cubic meter per hour, while for the deeper aquifers they are 10^{-4} cubic meter per hour.

More than 50 pressure values have been determined from pressure buildup curves registered during the production tests. It can be stated that hydrostatic conditions are typical for the Carboniferous aquifers to about 900-1000 m. The most lower aquifers to 1600 m are characterized by an overpressure of about 12-20%. The mean pressure gradient of the deeper aquifers is about 1.2 MPa/100 m, but the authors have the opinion that the gradient increases with the depth.

The anomal pressures also characterize some of the Tertiary aquifers located within the Alpine depression of the USCB at the roof of the Carboniferous coal deposits.

CHEMISTRY AND TOTAL MINERALIZATION OF GROUNDWATERS

The total mineralization of groundwaters in the deep Carboniferous aquifers varies from 40 to above 250 g/dm^3. The general trend of the increase of water mineralization with depth can be observed (3).

The brines of Carboniferous formations distinguish themselves by an elevated concentration of specific components such as: Ba^{2+}, Sr^{2+}, F^-, HBO_2, J^-, Br^- and also an elevated level of radioactivity in high mineralized groundwaters. The gaseous composition of brines is predominated by methane coming from coal beds degassing.

The value of the epm Na/Cl indicator is lower than 0.85 and that of the epm Na/Ca+Mg lower than 4, which means a high degree of diagenetic changes in brine.

Within the main syncline of the USCB the total mineralization of groundwaters in the Carboniferous aquifers depends on the lithology and thickness of the Tertiary overburden as well as mining activity only to the depth of 500 m. The influence of these factors in case of the deeper aquifers is not observed.

In the area of the main syncline the total mineralization of groundwaters, at the depth interval from 700 to 1500 m, ranges from 40 to 250 g/dm^3, while the hydrogeochemical gradient changes from 12 to 18 g/dm^3/100 m.

ORIGIN OF THE GROUNDWATERS IN THE LIGHT OF THE ENVIRONMENTAL ISOTOPES DATA

The waters sampled from deep Carboniferous aquifers show no tritium and ^{14}C presence. The $\delta^{18}O$ values range from -0.7 per mille to -4.93 per mille and δD values range from -3.6 per mille to 37.3 per mille. This group of waters create separate cluster at the precipitation line (Fig. 4).

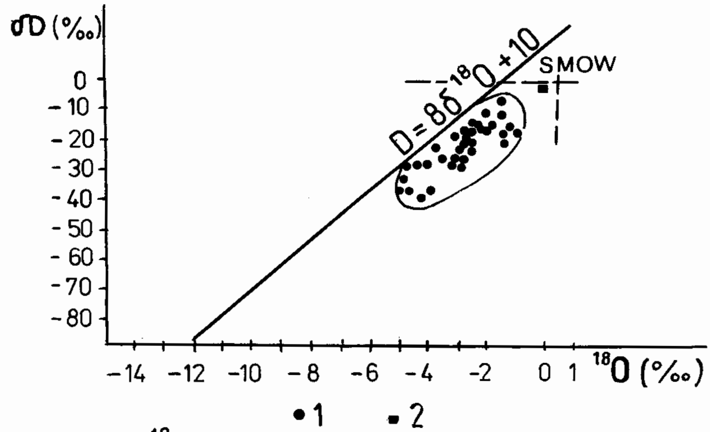

Fig. 4 $\delta^{18}O$ plotted against δD for upper Silesian Coal Basin waters

1- waters from the Carboniferous impermeable cover (depth 700-900 m), 2 - waters from the Tertiary formation

These waters are the mixture of relict waters of different origin (3). Mixed waters occuring in the roof link of the Carboniferous deposits are mainly Tertiary epigenetic ones. Pore waters from the argillaceous Badanian formations were squeezed out into the Carboniferous ones as a result of compaction and geodynamic pressure during the Carpaths lifting up. Chemical composition, anomal high mineralization (351 g/dm^3) in the vicinity of Tertiary salt deposit support this conclusion. The He-Ar method estimates age of these brines at 33-105 million years.

Relict waters formed during the older hydrologic cycles appear within the low Carboniferous links. They belong probably to paleoinfiltration waters of Permian age and partailly they may be waters resulting from the compaction and dehydratisation of the thick argillaceous marine Namurian and Visean complex.

Synsedimentary brines occur in the sandy inserts of the Badenian argillaceous deposits at the roof of the Carbonife - rous strata. $\delta^{18}O$ and δD values for this group of waters correspond to SMOW (Fig. 4).

CONCLUSIONS

1. The results of investigations point out that the hydrogeological parameters of deep aquifers within the USCB can be estimated using the field laboratory methods and tubular testers.

2. The deep aquifers of the productive Carboniferous formation within the USCB are characterized by very poor permeability and storage coefficients as well as very low water bearing capacity.

3. Projected deep mines at the depth of 700-1500 m will drain only non-renewable static resources of groundwater which are highly mineralized (90-250 g/dm^3). The water will be saturated with methane. The inflow of groundwaters to the mine workings from the Carboniferous aquifers will be only a few cubic meters per minute, with the tendency to decrease in time.

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