THE HYDROGEOLOGICAL PROPERTIES OF THE CARBONIFEROUS SANDSTONES IN THE SW PART OF THE UPPER SILESIAN COAL BASIN IN THE LIGHT OF THE LABORATORY RESEARCH

Andrzej Witkowski
Silesian University, Department of Earth Sciences
Sosnowiec, Poland

ABSTRACT

The present work contains the characteristics of the effective porosity, specific yield, permeability and the pore-size of the upper Carboniferous sandstones of the SW part of the Upper Silesian Coal Basin. This characteristics was presented basing on the laboratory research carried out on 460 samples of rock drawn from 11 boreholes. The variabilities of the discussed hydrogeological properties were presented depending on the stratygraphic position and the depth of sampling. The analysis of the variabilities was carried out in three variants taking into account: the depth from the surface of the area (Z_1), from the Carboniferous roof (Z_2) and the distance from the accepted correlation level (Z_3). The tendency to decrease the effective porosity, specific yield and permeability of the examined sandstones together with depth has been observed, this dependency being clearest when taking into account the distance from the correlation level (Z_3).

By means of the factor analysis (R method) an attempt has been made to establish the kind of factors and their role in shaping the observed variabilities. It has been observed that the differentiating of the total volumes of the open pores and their size being the result of both the diagenetic and weathering process has the decisive influence.

INTRODUCTION

The building of new coal mines requires the knowledge of not only geological but also hydrogeological conditions of the mining areas. To solve such problems as the size of the expected inflows, defining the anticipated time of dewatering as well as its range, it is necessary, among others, to know the hydrogeological properties of the rocks accompanying coal beds. This specific need influenced big interest of the researchers in the problems of hydrogeological properties of the Carboniferous rocks of the Upper Silesian Coal Basin. First, the majority of research was concentrated in the Eastern part of the Basin and, as a rule, covered the youngest complex of sediments, i.e. the so-called Cracow sandstone compelx (Z.Wilk, 1964, 1965, 1967; Z.Wilk and B.Szwabowicz, 1965; A.S.Kleczkowski and S.Witczak, 1967). In recent time there was a necessity to examine the SW part of the Basin in connection with the mining development of the coking coal deposits. There are practically no detailed studies concerning this part of the Basin. Gheral information in this field was, among others, presented in the work by Kleczkowski and others (1968) and Różkowski and Wagner (1986). These facts influenced the interest in the SW part of the Basin and the problems of the hydrogeological properties of the upper Carboniferous rocks occurring there.

THE GENERAL GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS

The research covered the area situated in the SSW part of Basin within the range of the so-called Main Syncline (Fig. 1).

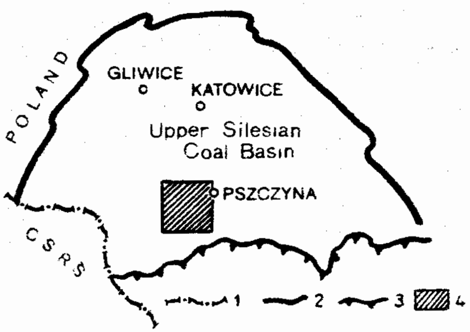

Fig.1 Localization sketch-map of the study area

1 - state frontier, 2 - border of the Upper Silesian Coal Basin, 3 - Carpathian overthrust
4 - study area

In the examined geological profile of the area there are Carboniferous, Tertiary and Quarternary formations. The productive Carboniferous formations consist of three lithostratygraphic series: the paralic complex - Namurian A (A.Kotas and W.Malczyk, 1972a), the Upper Silesian sandstone complex - Namurian B and C (A.Kotas and W.Malczyk, 1972b), the mudstone complex - Westfalian A and the lower part of Westfalian B (J.Porzycki, 1972). The productive Carboniferous formations are shaped in the form of sandstones and mudstones with numerous coal beds. In the profile the quantitative relationships between particular lithological types of rocks are varied. Generally, within the scope of the Upper Silesian sandstone series macroclastic formations dominate.

The Carboniferous waterbearing stage consists of a number of water aquifers connected with the strata of sandstones isolated from each other by intercalations of non-permeable mudstones. Locally, in the zones of the lithological wedgings out and tectonic disturbances there is a hydraulic tie between the aquifers.Carboniferous aquifers are of the porous-fissured type with changeable hydrogeological parameters.

THE SCOPE AND RESULTS OF THE RESEARCH

In order to obtain detailed data concerning the hydrogeological properties of the Upper Carboniferous sandstones of the discussed region 460 samples were examined drawn from 11 boreholes (Fig. 2). The carried out research covered the marking of effective porosity, specific yield, permeability and the pore-size.

To mark the effective porosity the method of saturating rock samples with liquid in vacuum has been used (A.Kleczkowski and St.Mularz, 1964). As a saturating liquid, however, not kerosene was used but brine 0.5%. To mark the specific yield the method of capillary drainage has been applied (T.Bromek, 1977) as well as the centrifuging method (J.Motyka and others, 1971). Rock permeability was marked by means of the gas permeameter constructed in the Main Mining Institute in Katowice (M.Rogóż, 1975). The pore-size measurements was carried out on 12 samples by means of the Quantachrome mercuric porosimeter in the Hydrogeological Laboratory of the British Geological Survey in Wallingford (Great Britain). The remaining markings were carried out in the Hydrogeological Laboratory of the Earth Sciences Department of the University of Silesia in Sosnowiec.

Effective porosity

The values of the effective porosity coefficients of the examined sandstones vary from 0.86% to 23.18% with the mean value of 8.01% and modal value of 4.52%. Over 50% of all samples has low effective porosity varying from 2% to 8%.

Analysing the obtained results depending on the lithostratygraphic complex one can observe certain regularities. The mudstone complex sandstones are characterized by the biggest effective porosity with their simultaneous highest variability (Tab. 1). The sandstones of the remaining two complexes generally have lower effective porosity and its smaller variability (Tab. 1).

Specific yield

The specific yield of the discussed rocks is also varied from 0.32% to 22.83% with the average value of 5.97% and modal value of 2.50% (Tab. 1). About 50% of all samples is characterized by very low specific yield not exceeding 4%. Only 11 out of 460 samples had specific yield over 18%. The latter can be considered as extreme and accidental.

The mudstone complex sandstones are characterized by the biggest specific yield and its biggest differentiation. The obtained values cover the wide interval of 0.43% - 22.83%. The lowest specific yield have the paralic complex sandstones (Tab. 1).

Generally, one can say that the general features of the specific yield variability considered depending on the age of the lithostratygraphic complex, are the exact reflection of the observed variability of the effective porosity.

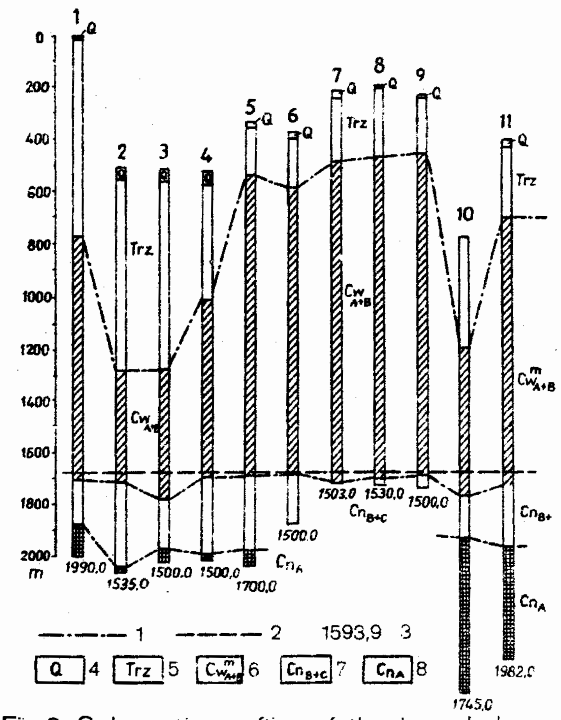

Fig.2 Schematic profiles of the bore-holes
1 - boundaries of the litological complexes,
2 - correlation level, 3 - depth belowe the surface [m],
4 - Quaternary, 5 - Tertiary, 6 - mudstone complex,
7 - Upper Silesian sandstone complex, 8 - paralic complex

	Mudstone complex				Upper Silesian sandstone complex				Paralic complex			
	max.	min.	$\bar{x}$	M_o	max.	min.	$\bar{x}$	M_o	max.	min.	$\bar{x}$	M_o
effective porosity (%)	23,18	0,86	10,21	10,78	9,34	1,26	5,25	5,13	9,67	0,93	4,22	3,33
specific yield (%)	22,83	0,43	8,24	7,33	6,98	0,45	3,09	2,92	7,64	0,32	2,09	1,38
permeability (mD)	310,47	0,004	22,675	-	1,68	0,006	0,287	-	0,48	0,023	0,197	-

Table 1. Characteristic values of particular hydrogeological parameters of the Carboniferous sandstones.

$\bar{x}$ – mean value
M_o – modal value

Permeability

The obtained permeability results (kp) vary widely from 0.004mD to 310.47 mD, so these are rocks from practically non-permeable to weakly permeable (according to Z.Pazdro, 1977). Over 80% of all the examined samples had permeability below 10 mD.

On the basis of mean values of the effective porosity, specific yield and permeability (Tab. 1) one can observe a clear tendency to decrease these values towards the stratygraphically older complexes. Big disproportion of the mean values of particular hydrogeological parameters of the examined sandstones between the mudstone complex and the remaining complexes is to be observed. It is particularly seen with permeability where the mean value for the mudstone complex is 22.675 mD and for the remaining complexe is about two orders of magnitude smaller. Within the mudstone complex we observe the biggest differention of the magnitudes of all the discussed hydrogeological properties. It is connected, first of all, with the widely understood weathering both mechanical and chemical. Mechanical weathering was mainly connected with the deconsolidation process, in other words, mechanical expansion of the mass rock due to lightening in the course of long-lasting denudation processes. Chemical weathering, on the other hand, could lead to the decomposition of both matrix and the basic components of rocks, such as feldspars and micas, the leaching of the decomposed substances and later their repeated falling out.

Characteristics of the pore space structure

On the basis of the carried out microsections and photographs from the electron microscope very varied shape and size of the pores in the examined sandstones have been observed. The shape of the pores changes from almost round to very oblong. They are often filled with the aggregates of the clay minerals. The size of the pores ranges from the thousandth parts of μm to the order of 200-500 μm. The fuller characterization of the pores with the diameters smaller than about 100 μm was carried out basing on the results obtained from the research on the mercuric porosimeter. The research was carried out on 9 samples of sandstones and additionally on 3 samples of mudstones drawn from different depths of a single borehole (A.Witkowski, 1986). The results of the research were set up in table 2. Pore-size distribution curves were also drawn (Fig.3).

Analysing the course of the curves one can generylly distinguish their three characteristic types.

The first type is represented by curves 1, 2, 3, 5 and 6. They characterize the homogeneous mudstone complex sandstones with effective porosity of the order of 11-14%. The sandstones are characterized by the biggest homogeneity of the size of pores. The medians of pores diameters vary from 0.25 μm to 2 μm.

The second type is represented by the curves characterizing samples 7, 8 and 12. They are characterized by the biggest non-homogeneity of the size of pores and refer to the sandstones of the Upper Silesian sandstone complex and the paralic series. These sandstones have low effective porosity of the order of 3-5%. The median of pores diameters is limited from 17.0 μm to 28.0 μm.

no of sample	lithostratygraphic complex	lithology of samples	V_c cm^3/g	S_w m^2/cm^2	d μm	d_{50} μm
1	mudstone complex	sandstone	0.0609	0.0612	9.17	2.000
2	- " -	- " -	0.0463	0.0816	5.37	0.350
3	- " -	- " -	0.0515	0.0462	10.60	0.250
4	- " -	mudstone	0.0134	0.0886	1.57	0.027
5	- " -	sandstone	0.0474	0.2720	1.61	0.300
6	- " -	- " -	0.0470	0.0626	7.12	0.450
7	Upper Silesian sandstone complex	- " -	0.0227	0.0104	22.66	20.000
8	- " -	- " -	0.0264	0.0154	17.43	17.000
9	paralic com.	mudstone	0.0143	0.0208	7.16	0.030
10	- " -	- " -	0.0071	0.0102	7.48	0.037
11	- " -	sandstone	0.0160	0.0518	3.16	0.077
12	- " -	- " -	0.0185	0.0076	25.35	28.000

Table 2. Compilation of the results of pore-size measurements of Upper Carboniferous sandstones and mudstones.

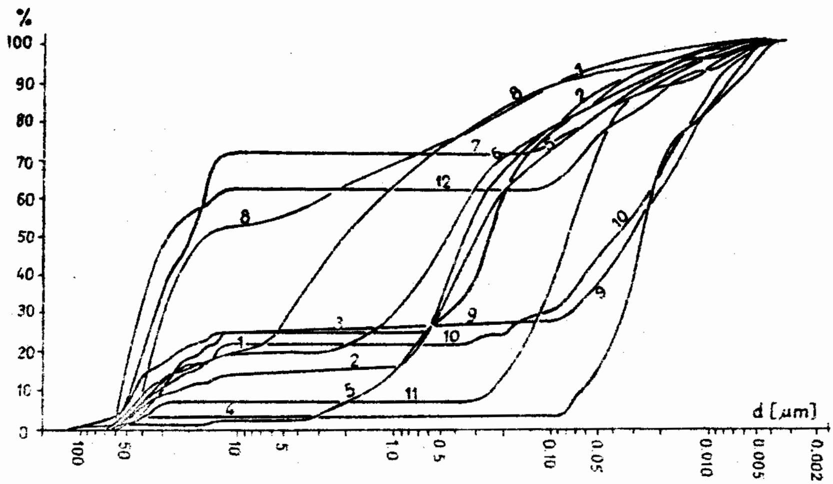

Fig.3 Pore size distribution curves
d - pore diameter 1-12- sample's numbers according to tab.2

The third type is represented [illegible]. They refer to the mudstones (4, 9, 10) and the non-homogeneous sandstones laminated with mudstones (sample no. [illegible]). The effective porosity of these rocks is low and varies from 3-4%. These rocks are characterized by the indirect non-homogeneity of the size of pores and very low values of the medians of pores diameters: from 0.027 µm to 0.077 µm.

VARIABILITY OF THE HYDROGEOLOGICAL PROPERTIES OF SANDSTONES WITH DEPTH

The problem of the influence of the depth of occurrence of the sedimentary rock for their hydrogeological properties was discussed by many researchers, among others: L.F.Athy (1930), J.Fatt (1958), H.N.Hall (1953), W.C. Krumbein (1942) and others. These authors observe the phenomenon of the decrease of porosity and permeability rocks with depth.

In Poland this problem was touched upon mainly by the researchers from Academy of Mining and Metallurgy in Cracow. Particular attention should be paid to the pioneer works of Z.Wilk (1960, 1965) and Wilk with Szwabowicz (1965). These authors observe the general decrease of the total and effective porosity as well as the Carboniferous sandstones permeability with depth. This variability is clearly connected with absolute depths calculated from the Carboniferous roof (Z.Wilk and B.Szwabowicz, 1965; A.Kleczkowski and others, 1976)

In the present work the sandstones of the older complexes of the Upper Carboniferous were analysed. The observed texture differentiation of the discussed sandstones having influence on their hydrogeological properties, caused the necessity to isolate the so-called homogeneous sandstones from the whole set of sandstones samples. To this subset belong sandstones with the homogeneous graining in which neither the gradual changes of fractions nor lamines nor inclusions of the coalified organic matter is observed.

The analysis was carried out in three variants examing the variability of a given hydrogeological property in the function of:

a) depth from the surface of the area (Z_1)
b) depth from the Carboniferous roof (Z_2)
c) distance from the correlation level which is the coal bed described by means of number 405 (Z_3).

The dependencies were approximated using polynomials of various degrees. The dependencies was best described by the second degree polynomials. As a result of calculations the nonlinear regression equations were obtained of the general form: $y = ax^2 + bx + c$. The correlation coefficients (R) were also calculated (table 3).

In order to display the shape of curves and the dispersion of points the diagrams of the variability of effective porosity of homogeneous sandstones in the function of depths from the Carboniferous roof (Z_2) and the distance from the correla-

[illegible] and [illegible] extreme degrees [illegible] interdependencies [illegible] have been presented (Fig. [illegible]

	effective porosity		specific yield		permeability	
	the whole population	homogeneous sandstones	the whole population	homogeneous sandstones	the whole population	homogeneous sandstones
Z_1	-0.635	-0.780	-0.664	-0.800	-0.385	-0.486
Z_2	-0.629	-0.733	-0.650	-0.750	-0.364	-0.439
Z_3	0.671	0.827	0.686	0.836	0.427	0.524
Number of markings	460	309	460	309	114	76

Table 3. Setting up the linear correlation coefficients (R) between the effective porosity, specific yield and permeability of the Carboniferous sandstones and depths from the surface of area (Z_1), from the Carboniferous roof (Z_2) and the distance from the correlation level (Z_3).

From the analysis of data in table 3 it results that the size of all the discussed hydrogeological properties of the Carboniferous sandstones is to a large degree dependent on the location of the sample in the depth profile. These dependencies are particularly observable for the isolated subset of homogeneous sandstones.

The above mentioned dependencies exist for all three considered variants (in the function of Z_1, Z_2 and Z_3). It is, however, the biggest in case considering the location of samples in reference to the correlation level (Z_3), and the smallest when considering depths from the Carboniferous roof (Z_2). These facts make it possible to assume that the biggest influence on the variability of the hydrogeological properties of the discussed rocks is exerted by their location in the stratygraphic profile. The lower correlation coefficients obtained for the depths from the Carboniferous roof are caused by very big differentiation of the described formation relief. The present shaping of the Carboniferous surface is the effect of tectonic process, and, first of all, erosion. The mudstone complex underwent particularly strong erosion. The effect of this is considerable differentiation of the thickness of this complex (Fig. 2). Two boreholes - no. 8 and no. 2 are exemplification of this. In the borehole no. 8 thickness of mudstone complex is as much as 1240 m when in the borehole no. 2, about 7.5 km distant from the previous one, thickness of this complex was reduced to 147 m (Fig. 2). Highly differentiated is also the depth of the location of Carboniferous roof which varies from 205.5 m (in the borehole no. 8) to 787.4 m (in the borehole no. 2).

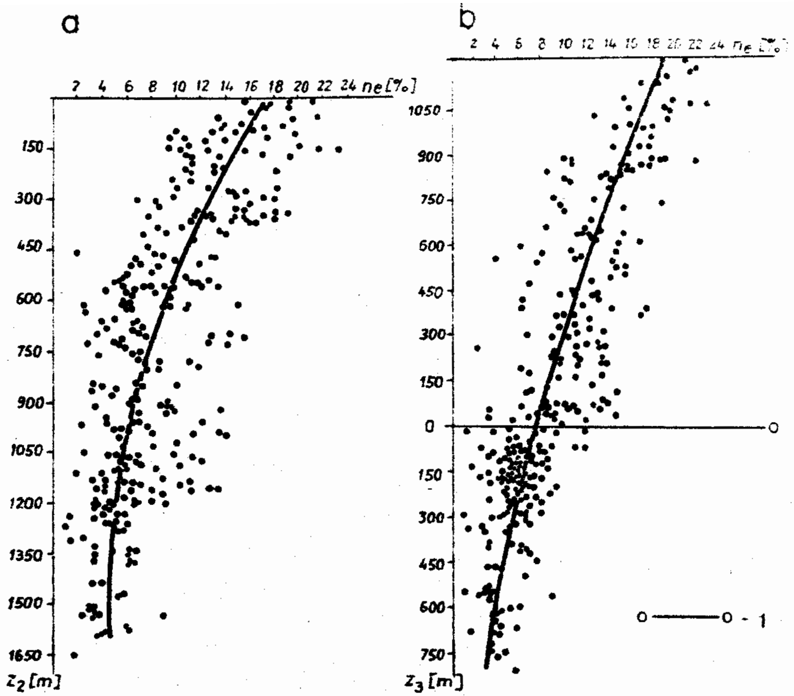

Fig.4 Dependency of the effective porosity coefficients (n_e) of the homogeneous sandstones on:
a) depth from the Carboniferous roof (z_2), b) the distance from the correlation level (z_3)
1 - correlation level

The observed decrease of effective porosity and of specific yield of sandstones with depth causes also the decrease of the draining degree in this direction understood as a relation of the specific yield coefficient to the effective porosity coefficient. The decrease of the draining degree value is a prove of the relative participation of bound waters increase in the general budget of waters occurring in the discussed rocks.

The presented differentation of the hydrogeological properties of the examined sandstones has been shaped under the influence of many factors, mainly of geological character. An attempt to define these factors and to establish their role in the shaping of the variability of the hydrogeological properties of the considered rocks was made basing on the so-called factor analysis. The analysis was carried out by means of Hotteling's method of principal axes - method R (J.Okoń, 1964). A collection of 614 samples of Carboniferous rocks defined by means of 16 changeable fearures underwent the analysis (A.Wit-

[illegible] 1982). Out of [illegible] samples taken for analysis, 460 were sandstones and the rest were mudstones. Such changeable features as: stratygraphy, lithology, the kind of matrix, texture differentiation, depth of sampling, thickness of formations younger than Carboniferous, distance from the closest dislocation zones, shape of samples taken for analysis, the obtained hydrogeological properties of rocks and their volumetric density were also taken into account.

On the basis of the obtained results one can observe that the decisive influence on 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 diagenetic processes, first of all, of sediments compaction and recrystallization processes as well as weathering processes. The latter are to be best observed within the most highly located mudstone complex. The reflection of the influence of these processes is the variability of the discussed properties in the lithostratygraphic profile of the Carboniferous formations. The second essential factor deciding on the differentiation of the hydrogeological properties is the content of the smallest fractions of grains in the considered rocks. This factor is closely connected with the structure of sandstones and mudstones. The growth of the content of smaller fractions causes the general decrease of the size of the considered hydrogeological properties. The third factor playing a certain role, though still not well examined, is the kind of matrix.

References

Athy, L.F., 1930, Density, porosity and compaction of sedimentary rocks, Bull. Amer. Assoc. Petrol. Geol., 14.

Bromek, T., 1977, Nowe metody ustalania współczynnika odsączalności i współczynnika ściśliwości objętościowej skał karbońskich, Ph. D. Thesis, GIG Katowice (unpublished).

Fatt, I., 1958, Pore volume compressibilities of sandstone reservoir rocks, Journ. Petrol. Techn.

Hall, H.N., 1953, Compressibility of reservoir rocks, Trans. AIME, 309.

Kleczkowski, A., Motyka, J., Wilk, Z., Witczak, S., 1976, Zmiany niektórych ocen hydrogeologicznych skał zwięzłych z głębokością, Przegląd Geol., nr 5, Warszawa.

Kleczkowski, A., Mularz, S., 1964, Przyczynek do metodyki wyznaczania porowatości skał dla celów hydrogeologicznych, Przegląd Geol., nr 2, Warszawa.

Kleczkowski, A., Vu-Ngoc-Ky, Zoń, S., 1968, Water permeability of the sandstones of the Upper Carboniferous in Upper Silesia, Bull. Ac. Pol. Sc., vol. 16, nr 2, Warszawa.

Kleczkowski, A.S., Witczak, S., 1967, Permeability and porosity of Carboniferous Sandstones as Related to Depth (East Upper Silesia), Bull. Ac. Pol. Sc., vol. 15, nr 1, Warszawa.

Kotas, A., Malczyk, W., 1972a, Seria paraliczna piętra namuru dolnego Górnośląskiego Zagłębia Węglowego, Prace Inst. Geol., Tom LXI, Warszawa.

Kotas, A., Malczyk, W., 1972b, Górnosląska seria piaskowcowa piętra namuru Górnośląskiego Zagłębia Węglowego, Prace Inst. Geol., Tom LXI, Warszawa.

Krumbein, W.C., 1942, Physical and chemical changes in sediments after deposition, Journ. Sed. Pet., 12.

Motyka, J., Szczepańska, J., Witczak, S., 1971, Zastosowanie wirówki do badania współczynnika odsączalności i dynamiki oddawania wody przez skałę, Technika Poszukiwań, nr 37, Warszawa.

Okoń, J., 1964, Analiza czynnikowa w psychologii, PWN Warszawa.

Pazdro, Z., 1977, Hydrogeologia ogólna, Wyd. Geol, Warszawa.

Porzycki, J., 1972, Seria mułowcowa piętra westfalu dolnego Górnośląskiego Zagłębia Węglowego, Prace Inst. Geol., Tom LXI, Warszawa.

Rogóż, M., 1975, Urządzenie do oznaczania przepuszczalności skał zwięzłych, Przegląd Górniczy, nr 7-8, Katowice.

Różkowski, A., Wagner, J., 1986, Reżim hydrogeologiczny głębokich poziomów wodonośnych w południowo-zachodniej części GZW, Prace Nauk. Inst. Geotech. Politechniki Wrocławskiej, Nr 49, Seria: Konferencje 21, Wrocław.

Wilk, Z., 1960, Zawodnienie górnośląskich kopalń węgla kamiennego i jego związek z warunkami geologicznymi, głębokością i wielkością kopalń, Geotech. i Hydrogeol., z.1a, Wyd. Geol., Warszawa.

Wilk, Z., 1964, Relation between porosity and depth of sandstones of the Łaziska and Libiąż Beds (Upper Carboniferous), Upper Silesia Coal Bassin, Bull. Ac. Pol. Sc., vol. 12, nr 2, Warszawa.

Wilk, Z., 1965, Zawodnienie a wielkość i głębokość kopalń we wschodniej części Górnośląskiego Zagłębia Węglowego, Prace Geolog. Komisji Nauk Geol. PAN Oddz. w Krakowie, nr 24, Kraków.

Wilk, Z., 1967, Rozwój i zmienność zawodnienia polskich kopalń węgla kamiennego, Zeszyty Nauk. AGH, nr 179, Kraków.

Wilk, Z., Szwabowicz, B., 1965, Badania laboratoryjne niektórych własnosci hydrogeologicznych piaskowców warstw łaziskich i libiąskich, Zeszyty Nauk. AGH, Geologia, nr [illegible], Kraków.

Witkowski, A, 1982, Zmienność porowatosci, odsączalności i przepuszczalności utworów karbonu produktywnego rejonu Pszczyna-Strumień (GZW), w świetle badań laboratoryjnych, Ph. D. Thesis, University of Warsaw, Warszawa (unpublished).

Witkowski, A., 1986, Charakterystyka struktury przestrzeni porowej skał górnokarbońskich południowo-zachodniej części GZW, Prace Nauk. Inst. Geotechn. Politechniki Wrocławskiej, No 49, Seria: Konferencje 21, Wrocław.