HYDROGEOLOGIC INVESTIGATIONS ON COAL DEPOSITS IN THE UPPER SILESIAN COAL BASIN (POLAND).

D.Grabowska
Geological Enterprise, Katowice
A.Różkowski
Silesian University, Sosnowiec

ABSTRACT

Planning of current coal mines as well as the extension of the old mines to new mining levels requires the hydrogeologic examination of the deposits for both economy and mine safety purposes.

The scope of the research methods used in the exploration of hydrogeological conditions of hard coal deposits, as well as a suggestion for improving research methods and widening the scope of studies interpretation have been discussed.

INTRODUCTION

Hydrogeologic investigations of the coal deposits are accompanied by the geologic exploration of the deposits. These investigations are being run in accordance with the Instructions setting forth the principles of establishing the hydrogeologic conditions in determining solid minerals reserves as well as with the Instructions specifying the principles and methods in determining solid mineral reserves.

The methods and problems connected with hydrogeologic investigations of hard coal deposits in Poland have been discussed in publications: Różkowski (1972), Różkowski, Wilk,Witczak (1972), Rudzińska, Różkowski (1980), Rudzińska (1983),Grabowska (1986). The recent years have seen the considerable extension of examinations applied in the hydrogeologic recording of the deposits mainly aimed at obtaining the largest possible amount of information on the water conditions in the prospect boreholes. The construction of new deep coal mines as well as new deep working levels in the existing mines made it also necessary to enlarge the scope of hydrogeochemical and isotopic methods being applied in the above investigations. The results of the hydrogeochemical and isotopic examinations are interpreted in the regional scale.

This paper presents and discusses the methods of hydrogeologic investigations now applied to the hard coal deposits in the Upper Silesian Coal Basin. These investigations are conducted by the Geological Enterprise of Katowice and by Upper Silesian Branch of Geological Institute at Sosnowiec during the exploratory survey and within the framework of the recording of coal beds in C, C_2 and C_1 category. Thus, the geologic exploration project is accompanied by the hydrogeologic exploration project whose extent corresponds to the category of deposit exploration.

HYDROGEOLOGIC DEPOSIT EXAMINATION IN BORE-HOLES

Hydrogeologic investigations of coal deposits being run in the Upper Silesian Coal Basin are targeted toward:

1- determing the location and arrangement of aquifers, their hydrogeologic characteristics, recharge and drainage areas, conditions of occurence and circulation of groundwaters, hydraulic conections between the aquifers as well as establishing the origin, quality and mineralization degree of waters.

2- forecasting the water inflows to the mining areas classified into those coming from dynamic and static resources during the main stages of mine development.

3- identifying the sources of water hazards for mining operations.

4- presenting the possible mining-induced, alterations in the natural arrangement of groundwaters and their impact on the interrelation between surface and groundwaters.

The hydrogeologic conditions of hard coal deposits are determined on the basis of investigations conducted in the single, bed prospect bore-holes or- in specific cases- in test wells. Said prospect holes are rotary drilled and their construction enables the hydrogeologic investigations to be conducted.

The intensification of hydrogeologic investigations in prospect bore-holes dates back from the year 1955. In the years 1955-1968 these investigations were conducted in cable-tool wells whose depth varied from 600 to 800 m. The investigations were carried out while the prospect holes were drilled. Test pumping methods were applied in case of prospect bore-holes with enlarged diameters.

The advantage of this investigating method consisted in the determination of the yield of aquifers under steady flow conditions at three depressions as well as in the possibility of drilling mud-free water sample being taken for physical and chemical analyses. This drilling system made it possible to measure the depth of drilling consecutive aquifers, the depth of dynamic water table in the course of investigations and the static water table on completion of investigations. The results as obtained were considered the most reliable and they were utilized in the preparation of hydrogeologic-deposit records of mining areas.

As the drilling technology was changed and cable drilling equipment was being retired, the hydrogeologic investigations were started in the rotary drilled prospect holes with light drilling muds. Such holes have up to 2200 m in depth and are

hardly suitable for test pumping method because of their smaller diameter, larger depths and due to the lack of pumps capable of meeting the necessary technical requirements such as diameter and delivery head. Since the drillings are made with fluid the hydrogeologic investigations are carried out after the drilling has been completed and the hole cleaned free from fluid. The investigations are started from the deepest aquifers deposited in the open portion of the hole below the casing and then they are conducted on shallow deposited ones within the lined portion of the hole. The aquifers deposited within the lined portion are made available for Testing by the perforation of the casing at predetermined depth levels.

The hydrogeologic investigations conducted in the fluid prospect holes cover hydrogeologic observations of the level and characteristics of the fluid. They include:

- control of fluid level in the supply tank,
- measurement and recording of the fluid level in the hole after each interruption in drilling lasting more than 24 hours,
- recording of changes in the characteristics of the fluid in the hole including its losses, dilution, salinity or gasification.

The investigations are made by test pumping or bailing methods, air pumps being used in sporadic cases only. The yield of the aquifers under investigation is measured at one depression or in very rare cases, at two depressions. As a rule the depth of hydrostatic level is established. At the final phase of test pumping of each aquifer water samples are taken for: 1- physicochemical analysis, 2- gaseous composition determination. In the recent years water samples are taken from predetermined holes for the determination of natural isotopes contents (T, ^{14}C, ^{18}O, ^{16}O, DH). Just after pumping the water is tested for its pH value and its temperature is measured.

The result of pumping conducted at the perforated casing are underrated due to limited availability of the aquifer as well as due to additional resistance of filtration caused by prospect hole walls being silted-up with fluid and rock-mass pores and fissures being partly covered in the course of casing cementing. Which is why corrective factors are employed making allowance for partial availability of the aquifer as well as for method and range of casing perforation (Litvinov,Blinov, 1964). Before the test pumping is commenced the prospect hole has to be cleaned. The cleaning operation is of significant importance from the standpoint of the representativeness of the water sample and reliability of testing results. The cleaning is made either by bailing or by pumping, and it is considered finished when the mineralization of water and its pH value are stabilized.

The application of drilling geophysics methods has proved very helpful in the determination of the aquifers. The set of geophysical measurements normally performed for the determination of the deposits was extended to cover:

- resistivity logs,
- spontaneous potential logs,
- fluid-resistivity logs with the fluid level in the hole being lowered several times,

- temperature logs.

In the first stage of application the interpretation of these measurement for water and gaseous purposes was of qualitative nature only. Now the quantitative interpretations are made to determine:

- lithologic profile of the strata drilled through in the prospect hole,
- depth of location and thickness of the aquifers,
- location of water outflows from the aquifers,
- specific resistance of the strata,
- temperature of the rock-mass strata,
- strata porosity coefficient,
- approximate mineralization of underground waters.

The methods of hydrogeologic investigations described above depend upon the drilling technology and measuring equipment. Lack of an adequate drilling equipment in combination with still increasing depth of prospect-holes having smaller and smaller diameters resulted in formation testers being introducted to the investigations in 1977. Such testers have been widely known in oil mining where they are utilized for sampling of oil- and gas-bearing horizons. During the first stage of application of this method at the "Kaczyce" mining area the investigations were made by means of KIJ-95 tester along the whole profile of the hole at 25-metre intervals. At the present moment this method is realized with the use of "Halliburton" tubular tester.

The investigations are carried out within the sandstone bands over 20 m in thickness, deposited mainly in the roof of balanced coal beds. Investigations of the deposits by means of the tester enables the hydrogeologic examinations to be carried out while the hole is being drilled, successively after the sandstone floor has been drilled through.

A particular advantage of sampling by means of the tester consists in a short time of testing and in a prompt quantitative estimation of the permeability of the rock within the hole area. The testing time of one aquifer does not exceed two hours. Interpretation of the tester-sampling results makes it possible to prepare a reasonably accurate characteristic of the following hydrogeological conditions prevailing in the aquifer under investigation:

- piezometric pressure,
- average output capacity,
- prospective output capacity,
- hydraulic conductivity (permeability).

The application of formation tester makes it also possible to take a water sample from the aquifer being tested. The problem of water sampling, however, has still to be improved having in view the pollution of water by drilling mud filtrate which is particulary the case when the inflow rates are low.

To identify and record the hydrogeologic conditions of the deposit the investigations of prospect-holes is accompanied by laboratory testing. These latter are performed in order to determine the hydrogeologic properties of the rocks and of the hydrogeochemical environment of the deposit together with its overburden. The hydrogeologic properties are tested on core-samples, mainly at field laboratories organized in the vicinity of prospect-holes. The testing program includes the determination of effective porosity, permeability and specific

yields of the sandstones. Effective porosity and permeability are determined at field laboratories by means of pressurized, mercury-operated porosity meter and by vacuum-method, respectively, whereas specific yield is tested by means of a centrifuge at stationary laboratories.

Geochemical investigations include the determination of the environmental alkalinity (pH) and of ion concentration in the ionic-salt complex of sandstone, on the basis of the water extracts.

Chemical examinations of waters from the aquifers being sampled are performed at stationary laboratories and provide information on mineralization, hardness and alkalinity of water, concentration of hydrogen ions, concentration of calcium, magnesium, sodium, potassium, iron, manganese and ammonia kations, concentration of hydrocarbonates, sulphates, chlorides, nitrates and nitrites, as well as the contents of gases such as hydrogen sulfide, carbon dioxyde and methane. Waters are also tested for their physical properties such as transparency, colour and odour. Physical and chemical examinations of waters make it possible to evaluate the chemical and physical composition of these latter from the standpoint of their possible utilization for drinking or industrial purposes but in particular they are helpful in the forecasting of salt concentration in the waters being running out from coal mines.

The prospect holes serve for additional determinations of isotopic composition of grounwaters (T, ^{14}C, stable isotopes) in order to find their age and origin.

In order to provide supplementary supporting data for the recording of water conditions of the coal deposits hydrogeological investigations on the site surface and hydrogeologic investigations of shallow groundwaters are being performed. These include the observations, measurements and sampling of surface and groundwaters. Their results will make it possible to forecast environmental changes induced by mining activities.

The results of hydrogeologic investigations are compiled in the form of prospect-hole records which include processed results of test pumping, tester exploration findings, interpretations of complex geophysical prospecting for hydrogeological purposes, hydrogeochemical and radiometric tests as well as of laboratory tests. The next phase of processing of the results are hydrogeologic elaborations making up the integral part of the geologic records of individual coal beds.

The analysis of the hydrogeologic investigations of the Carboniferous aquifers performed in the bore-holes has shown that their results frequently contain considerable errors. These latter are attributable to imperfect drilling techniques and to the testing methods being applied. Another important factor accounting for these errors is the lack of adequate equipment, which refers particularly to bore-hole pumps with small diameters and high delivery head.

The chemical analyses of water as obtained from hydrogeologic investigations are sometimes of doubtful reliability. The main reason there is the pollution of groundwaters with drilling fluid and intermixing of waters from different aquifers. The last case is attributable to imperfect technique of drilling and closing of the aquifers. The least accurate data on the chemistry and mineralization of waters are obtained from the samples provided by packer-testers. Estimation of water mineralization based on the chemical analyses of water extracts from the rock is likely to be developed in future.

A comparative analysis of the determination of filtration coefficient by means of test pumping and laboratory testing has shown that the latter is very good for this purpose. This, however is valid only for deep-situated Carboniferous aquifers where the fissure porosity disappears.

Fully reliable information on the water-bearing capacity of the Carboniferous aquifers is provided by test pumping methods only. Less accurate results are obtained from bailing and tester-sampling, the former being more reliable than the latter due to better bore-hole cleaning.

There is an imperative necessity for the increasing of the range of testing in wells in order to determine hydrogeologic characteristics under unsteady flow conditions.

APPLICATION OF HYDROGEOCHEMICAL AND ISOTOPIC METHODS IN HYDROGEOLOGIC INVESTIGATIONS OF COAL BASINS

Hydrogeologic investigations carried out in deep prospect-holes in the central and southern part of the Upper Silesian Coal Basin do not offer an explicit explanation concerning location of the coal deposits in the water flow system as well as the hydrochemical zonation system. New perspectives in this field are opened by largely extended application of hydrogeochemical and isotopic methods and paleohydrogeologic analyses (Różkowski, Rudzińska, 1983). The implementation of said methods considerably facilitates and sometimes renders possible the three-dimensional interpretation of the phenomena found on the basis of the investigations carried out pointwise in the prospect-holes.

The investigation of the hydrogeochemical environment of the coal deposit series and their overburden is carried out chiefly on the basis of the analyses of the chemical composition of water and rocks, as well as gas composition and thermal conditions of the water. Much attention is also paid to the results of determinations of the isotopic composition of water.

The results of the chemical analyses of water, sampled in the course of test pumping, are interpreted from the stand point of definition of the hydrogeochemical environment as well as the origin of water and its position in the circulation system. This interpretation is carried out with reference to the geologic and lithologic features of the structure under consideration.

The chemical classification of water is carried out according to the system of Scukariev-Priklonski and Schoeller based upon the content of cations and anions in water. Graphically, the chemical composition of water is mostly presented on diagrams of Piper, Schoeller and Brodski, and in the form of histograms.

The chemical classification of water is supplemented by quantitative ionic indices. The following indices are most often applied and they are the least controversial: r Na/r Cl, r Na/r Ca+Mg and r Cl/r SO_4. The ratios r Na/Cl and r Na/Ca+Mg are assumed as the index of diagenesis degree and of enrichment of the waters with Ca^{2+} and Mg^{2+}. The value of the first index below 0.85 and of the second index below 5 indicates an intense process of ion exchange between water and the rocks. The exchange processes occur in conditions of hydrodynamic stagnation and of isolation of the reservoir from the impact of infiltration water. High values of r Cl/SO_4 (i.e., those values over 100) indicate reducing conditions and the isolation of the groundwater reservoir.

The rate of increase in the mineralization of water is expressed quantitatively using the hydrogeochemical grade or hydrogeochemical gradient.

The examination of the hydrogeochemical environment of coal deposit in the Upper Silesian Coal Basin and of their overburden also are performed applying the method of water extracts (Kotlicka, 1971, Witczak, 1965, Herzig, 1985). The latter consists in extracting the ion-salt complex from a rock sample. The chemical composition of water extracts is presented in terms of ions or of hypothetical salts.

This method enables us to evaluate the depth of occurence of saline water and brine and to carry out a preliminary estimation of the hydrogeochemical conditions of the area.

In the scope of hydrogeochemical investigations of the coal basins, considerable attention is given to the gas composition of water. The gases dissolved in water constitute not only an important index of the hydrogeochemical environment, but they threaten seriously the mining operation. Hence it is essential to determine their concentration, chemical composition and pressure.

The determination of the gas content in water allows us to estimate the renewability of groundwater resources. Particular attention is given to the occurrence in water of biogenic "argonless" nitrogen, defined by the coefficient Ar/N_2 below 1.18 and of elevated contents of CH_4, as gases characterizing zones isolated from the influence of meteoric water. Conclusions in this subject are usually supported by detailed analysis of hydrogeologic conditions of the coal deposit area.

The elucidation of several hydrogeologic processes requires a knowledge of thermal conditions of groundwater environment. The thermal conditions of water are deduced from geothermal measurments carried out in bore-holes. Beside the temperature measure ment, the basic parameters that define the thermal field of a coal basin includes the geothermal gradient (grad. T=T/H) and the flow (Q=k x grad.T, where "k" denotes the value of thermal conductivity of rocks). The application of the described methods to determine the thermal field of coal basin is described in the papers of Chmura (1970) and Majorowicz (1975).

In hydrogeologic investigations of coal deposits of the Upper Silesian Coal Basin the isotope technique is being successfully applied (Różkowski, Przewłocki, 1974, Przewłocki, Różkowski, 1983). Particularly advisable are the methods based on the determination of the quantitative differences in the content of environmental isotopes in water, both the ratios of stable isotopes in water (D/H, $^{18}O/^{16}O$) and the level of radioactive ones (T, ^{14}C).

The main reason for the application of the isotopic technique is the fact that the considerable gradients in the isotopic content occur between saline water of the stagnation zone, on the one hand, and the presently existing meteoric water on the other. These differences may be correlated with the sampling depth, water mineralization and the position of water in the circulation system.

Tritium has been applied successfully in investigations of the age of water and its circulation under conditions of shallow coal deposits in hydrogeologically open structures (Frączek, Goszcz, 1971, Jureczko, 1974, Różkowski, 1985). The determination of the tritium content in water is also applied to control the interpretation of the determination of other isotopes, and to test the accuracy of sampling.

The results of measurement of the radioactive carbon ^{14}C is utilized to investigate the water conditions of coal deposits situated in the zone of restricted exchange. The results of measurements enable the determination of the age of waters and their origin indirectly (Jureczko, 1974b, Różkowski, 1985, Zuber, Grabczak, 1981).

The determination of the differences in ratios of stable isotopes D/H and $^{18}O/^{16}O$ is of particular significance for the classification of waters and the determination of their position in the flow system (Różkowski, Przewłocki, 1974, Przewłocki, Różkowski, 1983). Based upon the relationship between the $\delta^{18}O$ and δD values, according to the function $\delta D = 8\,\delta^{18}O + 10$, attempts are being made to establish the border between the zone of fresh or mixed waters and that of relict brines.

Particularly interesting results were obtained from investigations with the use of the environmental isotopes techniques when applied to problems of water in deep hydrogeologically

covered structures (Różkowski, Przewłocki, 1974, Przewłocki, Różkowski, 1983, Zuber, Grabczak, 1981). These investigations attempt to confirm the degree of hydrogeologic isolation of the coal deposits to determine the origin of the expected inflow of water to mines and to elucidate the possibility of renewal of groundwater resources.

The explanation of the hydrodynamic conditions and chemical composition of groundwaters of coal basin requires also the application of paleohydrogeologic analysis taking into account the course of orogenic and postorogenic processes.

References

Chmura, K., 1970, Własności fizyko-termiczne skał niektórych polskich zagłębi górniczych, Wyd. Śląsk.

Frączek, E., Goszcz, A., 1971, O możliwości zastosowania techniki izotopowej w badaniach hydrogeologii kopalnianej, Pz. górn., nr 4,: 190-195.

Grabowska, D., 1986, Warunki badań hydrogeologicznych dla rozpoznania i dokumentowania złóż węgla kamiennego w GZW, I Konf. nt.: Postęp naukowy i techniczny w geol. górn. węgla kamiennego, zesz. nauk. Pol. Śl., z.149: 383-390.

Herzig, 1985, Charakterystyka zasolenia chlorkowego pokładów węgla i skał otaczających w Górn. Zagł. Węgl., rkps. pracy dokt. Arch. AGH, Kraków.

Jureczko, J., 1974a, The application of tritium methods for investigating water hazards in the mines of the Upper Silesian Coal Basin, The application of natural radioactive isotopes in the hydrogeology, Katowice: 146-170.

Jureczko, J., 1974b, Studies on ^{14}C activity of water from deep coal mines of the Rybnik Coal Area in Poland, The application of natural radioactive isotopes in the hydrogeology, SITG, GIG, Katowice: 270-286.

Kotlicka, G.N., 1971, Mineralizacja kompleksu jonowo-solnego utworów karbońskich w rej. Brzeszcz na Górnym Śląsku, Biul. Inst. Geol., 249: 179-202.

Litwinow, A.A., Blinow, A.F., 1964, Promyslowyje issljedowania skważin, Niedra.

Majorowicz, J., 1975, Warunki geotermiczne w obszarze Lubelskiego Zagłębia Węglowego w rejonie Łęcznej, Pz.geol. nr 12: 614-620-

Przewłocki, K., Różkowski, A., 1983, Origin of groundwaters in the Upper Silesian Coal Basin according to stable-isotope composition, Isotope hydrology, IAEA, Vienna: 820-822.

Różkowski, A., 1972, Metodyka badań hydrogeologicznych złóż węgli kamiennych, Warszawa, Materiały z LXVII Sesji Naukowej IG: 102-114.

Różkowski, A., 1985, The influence of mining on the groundwater mineralization in the Upper Silesian Coal Basin, Mine Water, IMWA, Granada: 1015-1025.

Różkowski, A., Przewłocki, K., 1974, Application of stable environmental isotopes in mine hydrology on the example of Polish Coal Basins, Isotope techniques in groundwaters hydrogeology, IAEA, Vienna: 481-501.

Różkowski, A., Rudzińska, T., 1983, The application of hydrogeochemical methods, isotope techniques and paleohydrogeologic analysis in hydrogeologic investigations of the Polish coal basins, Geological problems of coal basins in Poland, Geol. Inst.: 362-418.

Różkowski, A., Wilk, Z., Witczak, S., 1972, Aktualne metody i problemy dokumentowania hydrogeologicznych warunków złóż węgla kamiennego, Inf. Techn. Ekonom., SITG z.3, Mysłowice: 1-27.

Rudzińska, T., 1980, Metody badań hydrogeologicznych złóż węgli kamiennych w Lubelskim Zagłębiu Węglowym, Metody i wyniki badań hydrogeologicznych złóż węgli kamiennych w Centr. Rej. Węgl. LZW, LXXXVII Sesja Nauk. IG, Wyd.Geol. 41-48.

Witczak, S., 1965, Określenie stopnia zasolenia wód karbońskich na podstawie badań wyciągów wodnych rdzeni piaskowców, Techn. Posz., nr 15/16: 53-57.

Zuber, A., Grabczak, J., 1981, Stable isotopes as a tool for age stratification of deep waters in the Lublin Coal Basin, AM- Union Symp. Isotop. in the Hydrosphere, Tallin.