CHEMICAL COMPOSITION OF GROUNDWATER IN THE FORELAND OF THE ČESKOSLOVENSKÁ ARMÁDA OPEN PIT LIGNITE MINE (NORTH BOHEMIA)

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ABSTRACT

Hydrochemical investigations in the foreland of the Československá armáda open-pit lignite mine, located in the Most part of the largest Tertiary basin below the Ore Mountains (the North Bohemian Lignite Basin), have been focused on the groundwater of 1. Quarternary deposits, 2. Tertiary basin sediments and volcanites, 3. crystalline complex in the basin's basement, and 4. crystalline complex of the Ore Mountains' slopes.

The chemistry of the above aquifers' groundwater is expressed by the $HCO_3:SO_4$ and Na:Ca hydrochemical coefficients, pH values and concentrations of the trace elements Li and F.

Based on these parameters, the vertical hydrochemical stratification of the sedimentary and crystalline complex can be determined.

The hydrochemical zonality, manifest by increasing pH values and Li contents, and by changing $HCO_3:SO_4$ and Na:Ca ratios for the benefit of hydrogen carbonates and sodium ions, towards the basin's basement, is preconditioned by the differing water retention times of individual aquifers, groundwater metamorphism in shallow aquifers due to acid rains, and the occurrenee of a formation, dozens of metres thick, of Tertiary clays and mudstones and/or degraded volcanites which act in the basin as a hydrogeological isolator separating the shallow aquifer from those located deeper.

INTRODUCTION

Development of Czechoslovakia's economic potential requires new energy sources. For this reason, lignite mining is being expanded in Tertiary lignite basins below the Ore Mountains.

The geological origin of these basins is analogous to that of lignite basins found on the GDR´s territory. The two basin systems are separated by the crystalline complex of the Ore Mountains, which forms the water divide and political borderline between the GDR and ČSSR (Fig. 1).

Earlier, coal in Tertiary basins was mined from underground mines. For economic reasons, this method of coal mining has been abandoned after 1945 and coal is now extracted from open pit mines. The square area of mining fields is enormous, amounting to some 850 km^2 in the North Bohemian Lignite Basin which is the largest and the most important lignite basin in ČSSR as well as one of the largest such basins in Western and Central Europe. The thickness of unproductive layers which must be removed prior to mining is up to 170 m in the studied region, i.e. in the foreland of the Československá armáda mine.

The areal extent and depth of the existing and planned open pits in North Bohemia and the coal mining itself considerably affect the geological, hydrogeological and ecological conditions in the region, and reflect also in the social sphere (evacuation of towns and villages, migration of population), consuming at the same time substantial economic and financial resources.

The planned opening of an approx. 200 m deep lignite pit in the foreland of the Československá armáda mine, having some 2 km long face, required, in view of the pit slope´s stability, verification of the effects of quarrying and mining on the hydrogeological system (particularly on the groundwater level), on the expected dewatering of the Ore Mountains´ slopes, and on the groundwater inflow into the pit´s bottom; also needed were engineering-geological, hydrogeological and geotechnical investigations in the pit´s locality and in the adjacent area of the Ore Mountains´s crystalline complex. Exploratory boreholes were drilled, level drifts were driven, and a monitoring system for monitoring slope stability and changes in the hydrogeological system was established. Investigations were supervised by specialists of Stavební geologie Praha, who also evaluate the measurement data.

The paper contains assessment of the hydrochemical investigation focused on the evolution of the groundwater chemistry in the studied region, in time and space, prior to the starting of the mining work itself.

1. INVESTIGATION METHODOLOGY

The groundwater chemistry was monitored in the period from 1982 to 1985.

The subject of monitoring was groundwater in exploratory boreholes and springs (Fig. 1a).

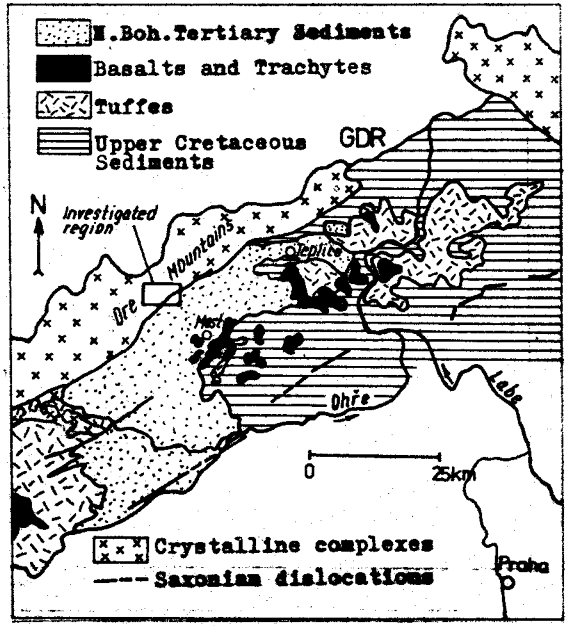

Fig.1. Geology of the surroundings of the region under study/after Kopecký,1962/

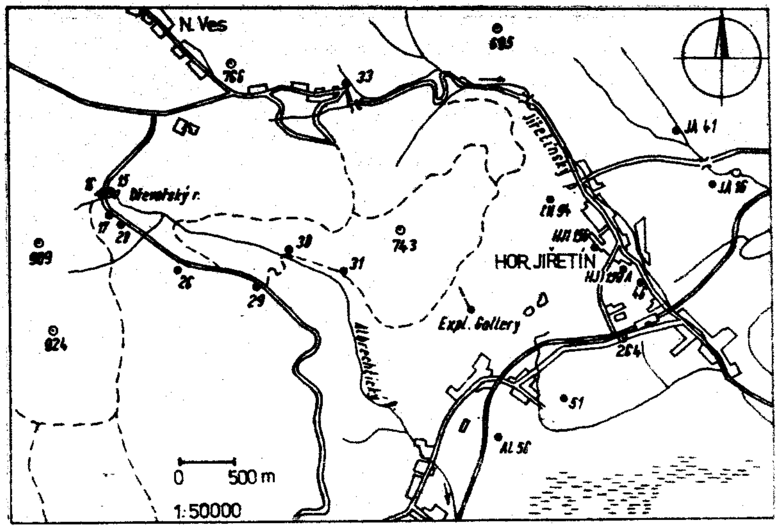

Fig.1a Investigated region;/•/ marks sampled sources

The design of the boreholes (aquifer isolation by cementing bridges) has made it possible to examine the quality of water separately from Quarternary deposits, the Tertiary formation sediments, Tertiary volcanites and the basement and mountain crystalline complex. Spring water analyses have helped to study the chemistry of the shallow aquifer forming in the talus covering the Ore Mountain's crystalline complex.

Samples of water from boreholes having a positive piezometric niveau were taken from the overflow, while boreholes with a negative niveau were sampled during pumping tests.

Springs and overflow boreholes were monitored over the long term, at approx. monthly intervals.

The water samples served for the determination of the contents of primary and secondary cations and anions, some trace elements, H_4SiO_4 and pH. The sum of the absolute ion and H_4SiO_4 contents represents the Total Dissolved Solids (TDS) value. For springs and the overflow borehole JA16, the analyses were completed with the determination of the temporal development of the sulphate sulphur isotopes ratio $^{34}S : ^{32}S$, expressed as $\delta^{34}S$.

2. INVESTIGATION RESULTS

2.1. Chemistry of the shallow aquifer's groundwater

2.1.1. Springs

Thirty-three talus springs were monitored, and their chemical properties found to be similar: the primary ions included alkali earths (Ca, Mg) and sulphate ions, exceptionally also hydrogen carbonate ions (Fig. 2). The pH was usually lower than 7.0. The TDS content was rarely over 200 mg/l. The equilibrium partial pressure of CO_2 (p_{CO2}) calculated from HCO_3 activity and the pH value for the representative springs Nos.15 and 46 amounted to $3.3 \, . \, 10^{-4}$ and $5.5 \, . \, 10^{-3}$ MPa resp.

Changes in the sulphate content and the groundwater pH were found, depending on the altitude of sampling and its distance from the groundwater divide (Fig. 3). The sulphate content increase towards the basin is obvious from the diagram.

The average values of $\delta^{34}S$ ($\simeq +3‰$) for sulphates of the representative mountain as well as foothill springs corresponded to those for precipitation water in areas with intensive firing of fossil fuels (Šmejkal, 1986).

In the 1982-1985 period, the ion contents in monitored representative springs did not show any regular rise or decline (Figs. 4 and 5); only short-term, periodic changes in pH (Fig. 4) and in the TDS content (Fig. 6) were observed.

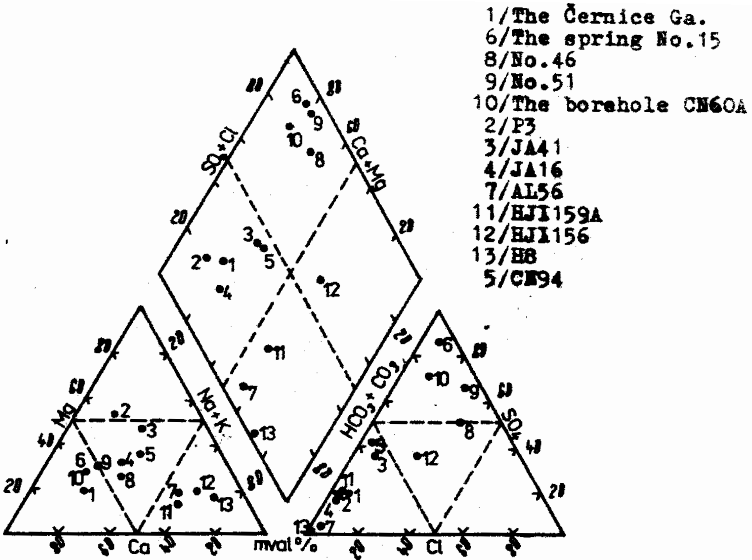

Fig.2. Analysis of groundwater in the investigated area as represented in trilinear diagram/after Piper,1949/

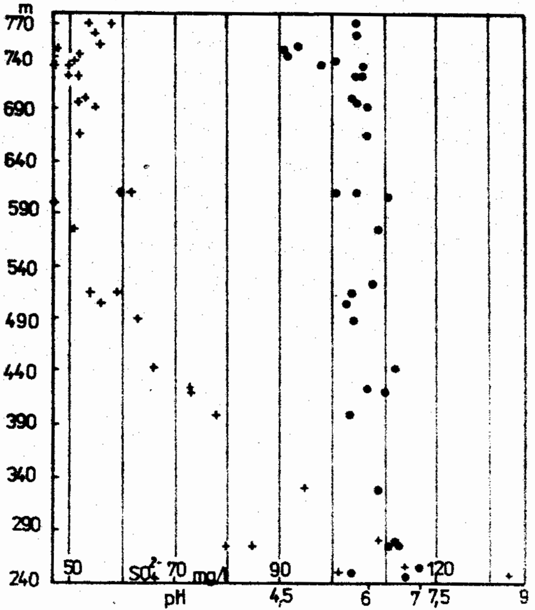

Fig.3. Relationship between the springs altitude, and average pH values and SO_4^{2-} /+/ contents

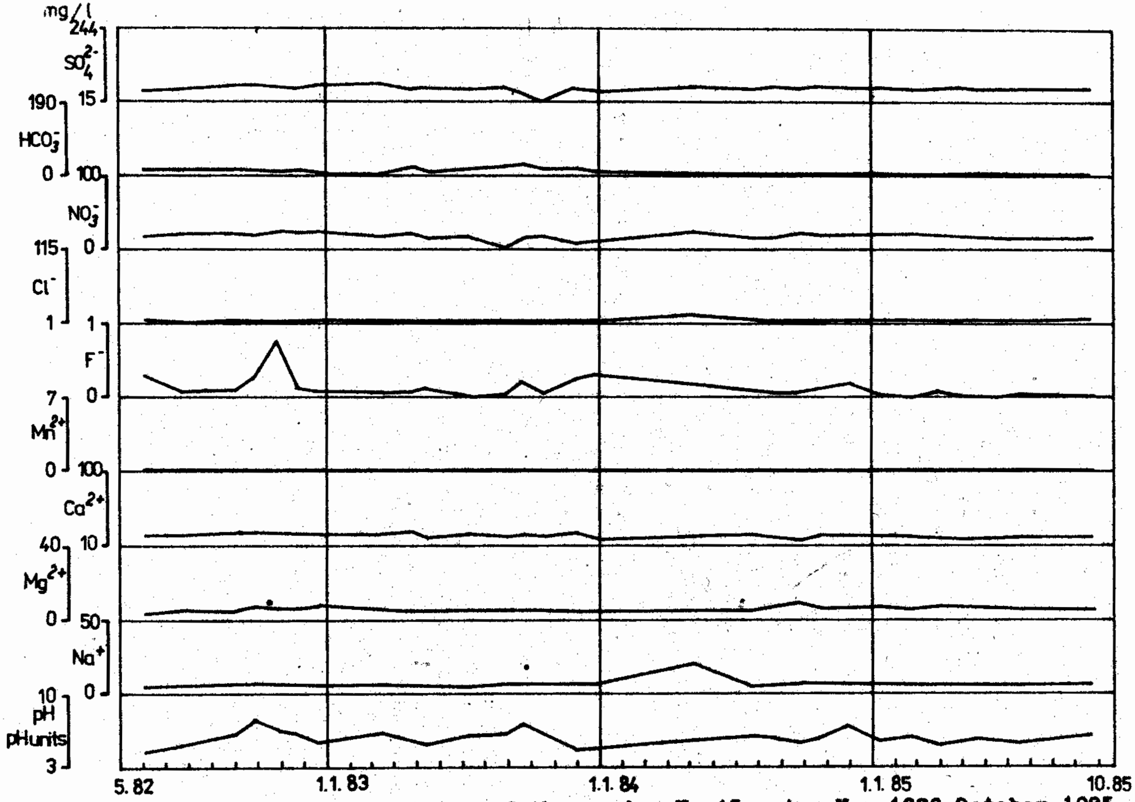

Fig.4. Chemical composition of the spring No.15 water, May 1982-October 1985

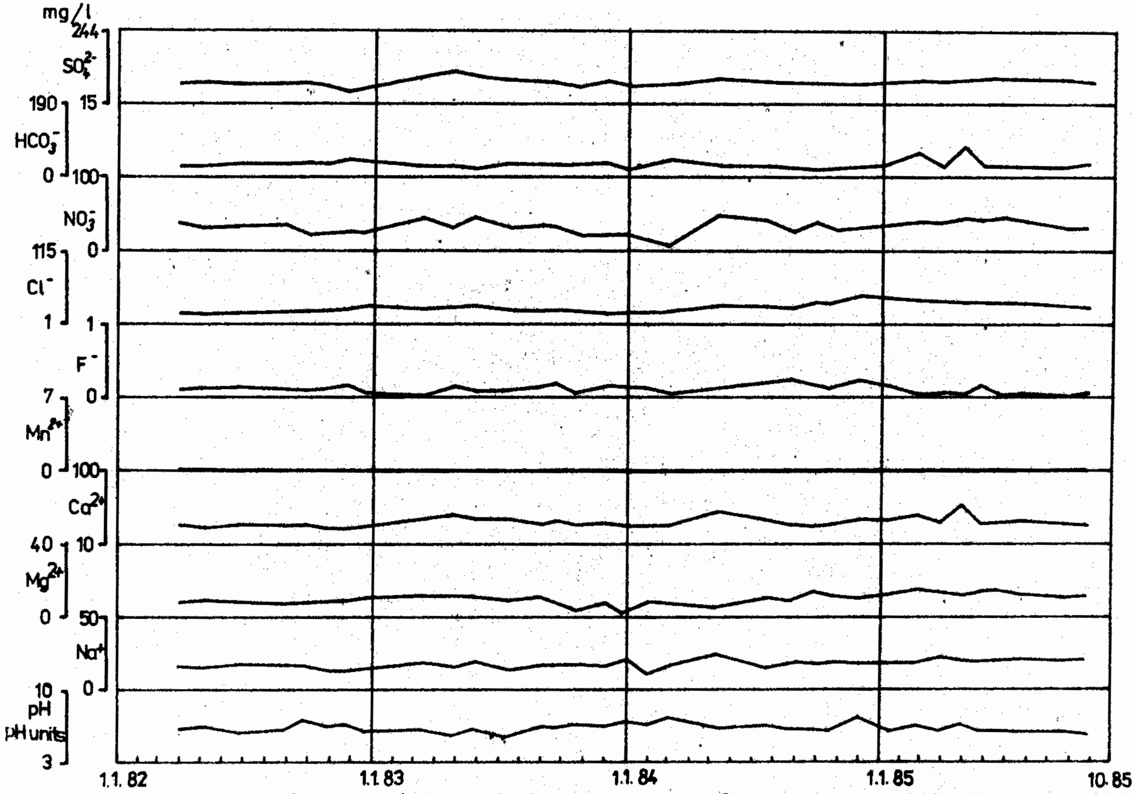

Fig.5. Chemical composition of the spring No.46 water, March 1982–October 1985

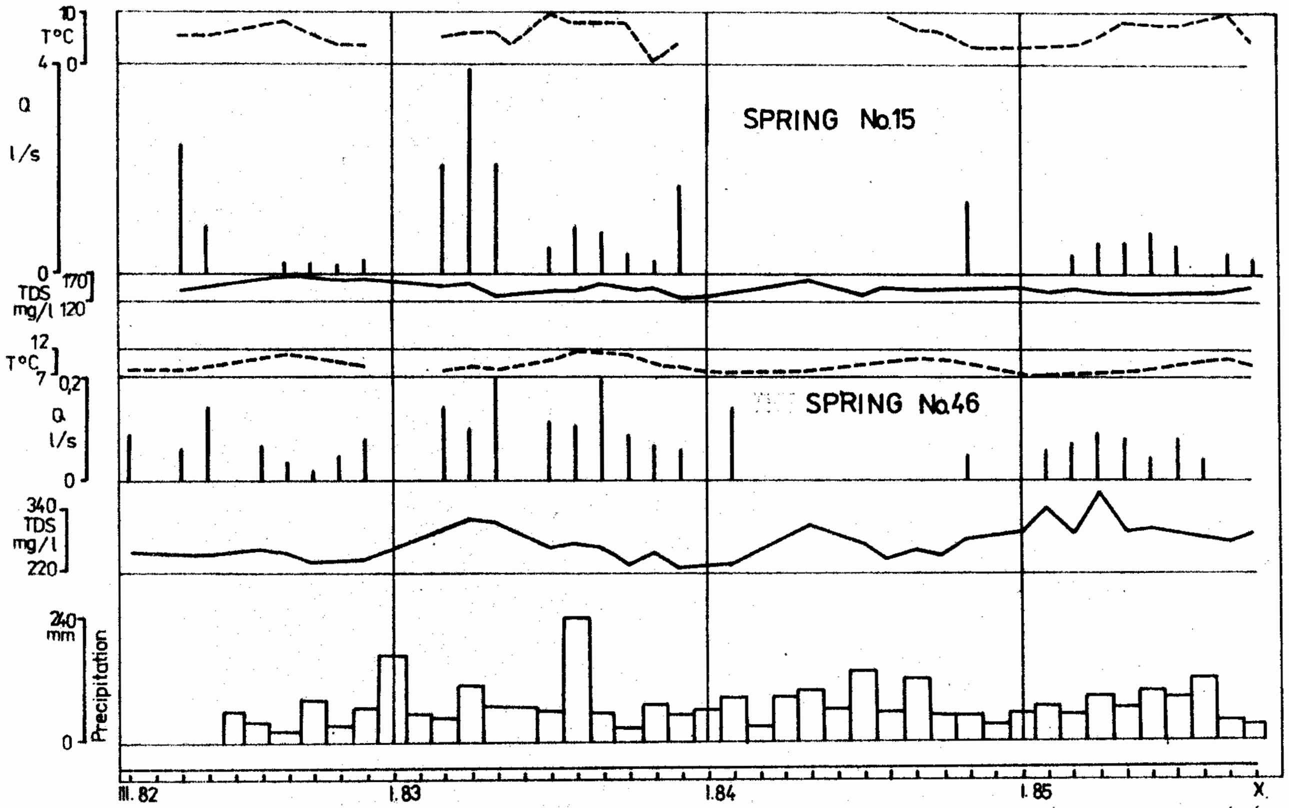

Fig.6. Monthly precipitation totals and seasonal changes in the TDS content,discharge/Q/ and temperature of the springs Nos. 15 and 46,March 1982 through October 1985

Table 1. Vertical hydrochemical profile and selected hydraulic parameters (average values) of groundwater aquifers in Quarternary deposits, Tertiary formations and the crystalline complex

	TDS mg/l	pH	HCO_3/SO_4	Na/Ca	F^- mg/l	Li^+	$\delta^{34}S$ ‰	T °C	Q (l/s) l/s/m	K_f m/s
					Spring No. 15					
	145	5.8	0.2	0.3	0.12	0.003	+3.06	5.9	(1)	
					Spring No. 46					
Quarternary	273	6.4	0.4	0.5	0.11	0.006	+3.07	8.9	(0.09)	
					Boreholes					
	288	6.4	0.4	0.4	0.16	0.02		10.4	1.02	$9.8.10^{-5}$
					Upper clays					
	380	6.9	20	5	0.02	0.31			0.15	
					Coal seam					
Tertiary	331	8.2	2	0.8	0.22	0.09		13	0.01	$1.4.10^{-7}$
					Basement sandstones					
	324	7.4	6	2	0.76	0.14		18.4	0.003	$1.2.10^{-6}$
					Volcanites					
	328	7.0	5.5	2	0.2	0.05	-1.42	11		$1.1.10^{-6}$
					Basement					
Palaeozoic	411	7.1	15	3	0.24	0.27		15	0.002	$3.1.10^{-8}$
					Mountain crystalline complex					
	256	7.3	6.5	1.5	0.52	0.04		11	0.024	$1.2.10^{-6}$

2.1.2. Boreholes

Thirty-seven analyses of water from 25 boreholes having open sections, in the shallow aquifer 2 to 15 m under the surface were evaluated.

The chemical properties of the borehole water corresponded to those of the spring water from the Ore Mountains' foothills (Figs 1 and 2, Table 1). Again, ions of alkali earths (Ca, Mg) and sulphates predominated, while hydrogen carbonates occurred as an exception. The p_{CO2} value of water (the CN60A borehole) was $5.1 \, . \, 10^{-4}$ MPa.

2.2. Chemistry of the Tertiary formation groundwater

2.2.1. Overlaying clays and mudstones

Only two water samples were analyzed, obtained during the drilling of the AL56 borehole. The samples were taken from the overflow (0.15 l/s), from a depth of 35 m.

When compared with the Quarternary aquifer, the chemical composition of this water was found to be different (Table 1). Here the dominant ions were sodium and hydrogen carbonate, the TDS content was 380 mg/l, and the pH value was 6.9. The p_{CO2} value for the groundwater from overlaying clays was $3.1 \, . \, 10^{-3}$ MPa.

2.2.2. Coal seam

Only one water sample was analysed; it was taken during pumping from the HJI 157 borehole (open section, 93 to 127 m).

The coal seam groundwater's chemistry differed from that of the shallow aquifer. Calcium and hydrogen carbonate ions predominated in the sample, the TDS content was 331 mg/l, and the pH value was 8.2. The p_{CO2} value of the coal seam water was $6.3 \, . \, 10^{-5}$ MPa.

2.2.3. Basal sandstones

Six groundwater analyses were obtained from five boreholes having open sections from 180 to 190 m.

Sodium and hydrogen carbonate ions predominated in the samples. Average TDS content was 324 mg/l, pH was 7.4, and the p_{CO2} value (the HJI 159A borehole) was $1.2 \, . \, 10^{-4}$ MPa.

2.2.4. Volcano-detrital formation

In this formation, water was sampled in six exploratory boreholes, four of them with overflow. Three overflow boreholes, JA41, P3 and S106, were drilled in the exploratory drift (Fig. 1a).

Alkali earths (Ca, Mg) and hydrogen carbonates predominated in all of the samples. Except for the JA16 borehole, the Ca:Mg ratio of all samples was lower than 1, i.e. inverse to that of the groundwater circulating in an acid, alumosilicate medium (e.g. gneisses in the basement of the Tertiary formation). The average p_{CO2} value for the volcanic formation was found to be $2 \cdot 10^{-3}$ MPa.

The volcanite water chemistry was monitored in the JA16 overflow borehole at approx. monthly intervals (Fig. 7) . In this borehole water from volcanites (olivine basalts) was collected together with the gneiss water in the 42 to 81 m section. The borehole overflow was 0.77 l/s, and the water had a stable temperature of 13.4°C. Fig. 7 shows the stable chemical composition of the water. The aquifer's isolation was verified by correlation analysis. The borehole water was compared with the water from selected mountain and foothill springs as to the contents of sulphates, hydrogen carbonates, chlorides, nitrates, fluorides, sodium, calcium and magnesium ions, and pH. At the level of significance 0.01, positive correlation was found between the JA16 borehole and spring No. 46 only, based on the Mg content. The Spearman's coefficient of correlation was +0.7.

The $^{34}S:^{32}S$ ratio also showed stable values. The average $\delta^{34}S$ value was -1.42‰ (V=9%, n=9). This value, different as it is from those of the springs, indicates the isolated groundwater circulation as well.

2.3. Basement rocks of the basin's sediments

In the region under study, the basement of the basin's sediments is mainly composed of muscovite or two-mica oriented orthogneisses. Isolated occurrences of biotite paragneiss. In their upper stratas, the basement rocks are subject to process of kaolinization.

Five boreholes with open sections 140 to 190 m were sampled. The dominant ions were sodium and hydrogen carbonates, the TDS content was 411 mg/l, and pH was 7.1. The p_{CO2} value was $8 \cdot 10^{-4}$ MPa (the HJI156 borehole).

2.4. Mountain crystalline complexes

In terms of petrography, the Ore Mountains' crystalline complex in the studied region is identical with the basement of the Tertiary sediments. In its upper part, processes of sericitization and chloritization were registered most frequently, and it is assumed that during the formation of the Ore Mountains the kaolinized profile of the crystalline complex had been carried to the basin's sediments.

Evaluated were 14 analysis from 11 hydrogeological boreholes, most of them drilled at the foot of the Ore Mountains. The boreholes have open sections from 18 to 100 m. This set also

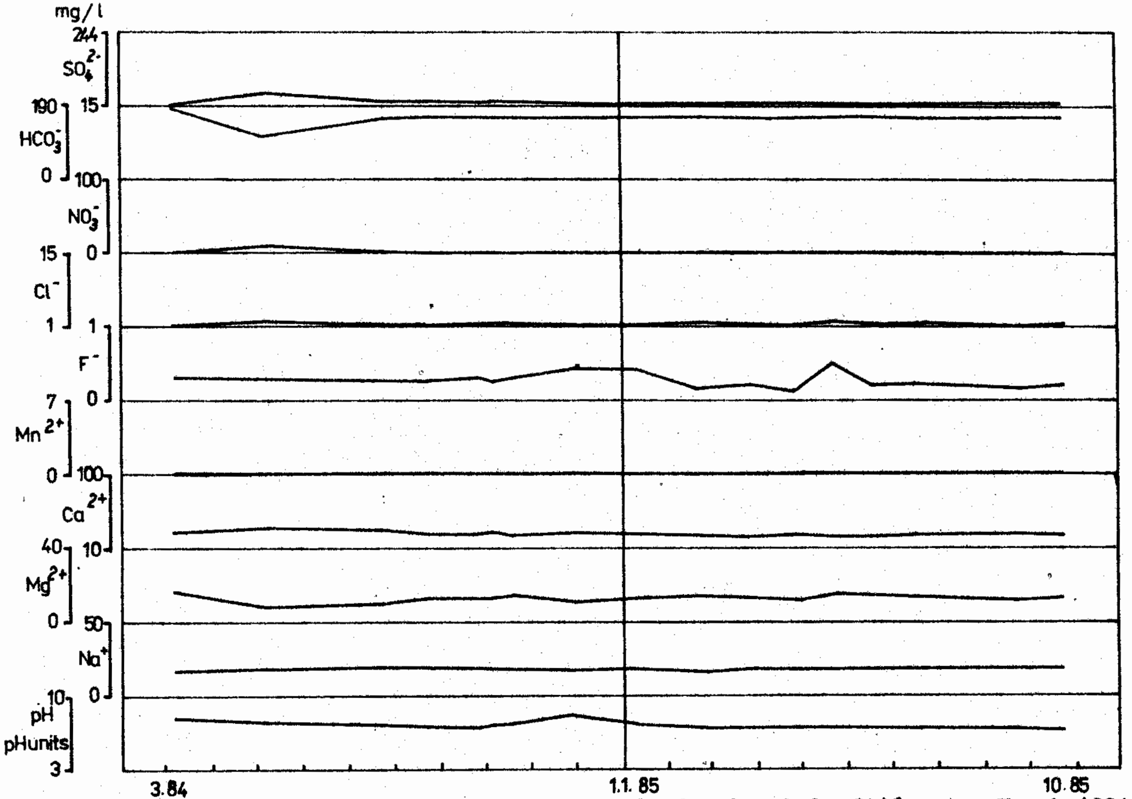

Fig.7. Chemical composition of the overflowing borehole JA16 water, March 1984 through October 1985

contains analysis of water inflows from the gneisses in the top wall of the exploratory drift (Fig. 2, point 1) and analysis of water from the overflow borehole CN94 (overflow 0.05 l/s, temperature 9.5°C).

The dominant cations were either calcium or sodium, while hydrogen carbonates were the main anions. The p_{CO2} value for the overflow borehole CN94 was $3.2 \cdot 10^{-4}$ MPa.

This water differed from the one in the crystalline complex in the basin's sediments in that the TDS content and the $HCO_3:SO_4$ ratio were lower, and the Li content was lower by nearly one order. The hydraulic parameters of the two aquifers, determined by means of hydrodynamic tests, were also different (Table 1).

4. DISCUSSION

In the region under study, composed of Quarternary deposits, Tertiary sediments of the Most Basin, and the crystalline complex of the adjacent Ore Mountains massif and the basin's basement, three basic types of groundwater have been identified over the vertical profile and the areal distribution of the chemical properties, namely: groundwater of the shallow aquifer in Quarternary deposits, aquifer in the Tertiary volcano-detrital formation, and the aquifer common to both the Tertiary basal sandstones and the crystalline complex of the basin's basement.

The shallow aquifer's chemical properties are caused by the presence of sulphate and hydrogen ions from acid precipitation; the latter has been monitored in the region since about the mid-1970s. Moldán (1980) mentions average pH of 3.82 for precipitation water in Most, and an 18.3 mg/l content of SO_4^{2-}. The pH value is markedly lower than the value 5.66 listed for the pH of precipitation water unpolluted by emissions, in which the hydrogen ions' activity results from the chemical balance between atmospheric water and carbon dioxide whose natural content in air equals 0.03% vol. (Pačes, 1984).

The strong effect of acid rains on the shallow aquifer's groundwater was monitored particularly in certain mountain springs discharging at an altitude of about 700 m a.t.s.l. The effect of acid rains, the small thickness of the unsaturated zone and the short retention time of groundwater in gneiss talus (consisting mainly of alumosilicates which are resistant to chemical weathering) are especially manifest in the low average pH values of these springs (as low as 4.4). A higher pH of mountain springs was observed only in periods with low precipitations, usually in October. In springs discharging at lower altitudes, higher average pH with no marked fluctuations was measured between 1982 and 1985 (6 to 7). The chemical composition of these springs' water is the result of its longer contact with the rock. The dominant anions, sulphates, have their origin in precipitation water (according to the isotope analysis of sulphate sulphur).

The low pH (6.4) and $HCO_3:SO_4$ and Na:Ca ratios (lower than 1 on the average) of the water in the shallow aquifer in Quarternary deposits tested, are associated to the springs in the foothills of the Ore Mountains. This water, too, is dominantly affected by acid rains.

The chemical properties of the water in deeper aquifers of the Tertiary formation and the basement crystalline complex indicate their hydraulic isolation from the shallow aquifer. These aquifers' coefficients of filtration and specific yield are as much as four orders lower than those of the shallow aquifer in Quarternary deposits. Their chemistry is the result of the meteoric water/rock interaction under low partial pressures of CO_2. Consequently, the groundwater has a higher pH (7.5), contains mainly sodium and hydrogen carbonate ions, and its TDS content amounts to 200 to 500 mg/l. The lower content of dissolved salts is proportional to the low leaching ability of this water under relatively low partial CO_2 pressures - between $1.2 \cdot 10^{-4}$ and $3 \cdot 10^{-3}$ MPa; these values correspond to the p_{CO_2} of the soil air under Central European climatic conditions ($5 \cdot 10^{-4}$ to $1 \cdot 10^{-2}$ MPa; Gazda, Pačes, 1975).

An example of groundwater chemism in an alumosilicate medium under higher p_{CO_2} are carbonated mineral waters issuing from the crystalline complex in the basement of the Most or Chomutov Tertiary basin. In 1985, near Kadaň on the fringe of the Chomutov Basin, carbonated mineral water was tapped by the H8 borehole. Its TDS content is 2.8 g/l, dominant ions are Na^+ and HCO_3^-, pH 6.7, free carbon dioxide content is 660 mg/l, and its temperature is 17°C (Fig. 2). Salts are dissolved in the mineral water at a p_{CO_2} of 0.03 MPa. More intensive dissolution also results in higher contents of alkali metals Li^+ (1.1 mg/l) and Rb^+ (0.13 mg/l).

Judging from average pH values of approx. 7.0 and the $HCO_3:SO_4$ ratio greater than 1, the groundwater in the Tertiary volcano-detrital formation and in the Ore Mountains' crystalline complex is relatively well isolated from the shallow aquifer and has no direct contact with acid rains. According to the Na:Ca and Na:Mg ratios approx. equal or lower than 1 for the volcanite water, these aquifers can be assumed to have a faster circulation of groundwater as compared with the aquifer in the basement crystalline complex. The dominant cations' content in the volcano-detrital formation groundwater (Mg^{2+} ions) is the result of the water's reaction with rock composed mostly of dark minerals and basic felspar and documents the groundwater's chemism in a medium which is petrographically different and hydrogeologically isolated from the other aquifers.

5. CONCLUSIONS

Hydrochemical investigation has been carried out in the foreland of the Československá armáda open pit mine located in the Most region of the North Bohemian Lignite Basin.

The investigation concerned groundwater quality in Quarternary deposits, Tertiary formation sediments and the crystalline complex in the basin's basement and the adjacent Ore Mountains massif.

Vertical hydrochemical zonality has been identified, manifest by increasing Li content, changing $HCO_3:SO_4$ and Na:Ca ratios for the benefit of hydrogen carbonate and sodium ions, and increasing pH. Three basic types of groundwater have been identified:

1. shallow aquifer in Quarternary deposits
2. aquifer in the Tertiary volcano-detrital formation
3. aquifer in the Tertiary basal sandstones and the basin's crystalline basement.

The differences in investigated aquifers' chemical properties are due to the metamorphism of the shallow aquifer caused by acid rains, different durations of meteoric water's contact with rocks having different petrographic composition, and the occurrence of an up to 170 m thick formation of Tertiary clays and mudstones which separate the shallow aquifer from those located deeper, acting at the same time as a hydrogeological isolator.

The results of the investigation are expected to be used for regional monitoring of the changes in the geochemistry and ecology of the Ore Mountains region's landscape which is affected by the wet and dry acid fallout generated by industrial agglomerations and mining. The investigation will also facilitate identification of waters inflowing into the coal pit during mining and help to design protection against the water's corrosive effects on building materials and the metal structures of mining and pumping equipment.

6. REFERENCES

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