EVALUATION OF THE GROUNDWATER CIRCULATION IN THE FOREFIELD OF AN OPEN PIT MINE ACCORDING TO THE ANALYSES OF TRITIUM

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ABSTRACT

The circulation of groundwaters in connection with the mining activities was studied in the contact region of the slopes of Krušné hory /mountains/ with the forefield of the brown coal open pit ČSA. Groundwater samples were drawn from bore-holes during the years 1977-1979. The specific activity of tritium as a natural radionuclide was measured in these waters. Regular investigation of the tritium activities contributed to the improvement and correction of knowledge concerning the circulation of groundwaters in the first /quaternary sediments/ and second /bedrock psammites and gneiss/ water-bearing collectors. By means of the isotope analyses, it was possible to check the cross tectonics at the outlets of mountain valleys into the tertiary basin. The flow velocity of groundwater to the distance of 140 m in the region of crystalline rocks was calculated for the profile of the brook Vesnický potok. The resulting time is, according to tritium analyses 18-22 years and according to observations 16-20 years. Both calculations confirm the very slow flowing of groundwater in the upper weathered part of crystalline rocks including the quaternary cover. Effects of the mining activities on the circulation of groundwater could not be confirmed outside the basin territory. The weathered zone of crystalline rocks in the bedrock of the tertiary basin has the function of an insulator. This conclusion is of great importance for the extraction of the coal seam. Owing to the high piezometric stress of the collector /bedrock psammites/ on the basis of the coal seam, it proved necessary to relieve this stress by water drainage. Isotope analyses were used to control, whether there are some inflows of water from the overlying collectors into the drained one. Results of the applied method of natural radionuclide are in good agreement with classical determination methods. The measurement of tritium activities induced also an alteration of the sample drawing procedure.

INTRODUCTION

The North-Bohemian brown-coal basin is of primary importance for the development of Czechoslovak power supply. This coal deposit abutes sharply, on its NW part, on the mountain chain of Krušné hory /Ore Mts./. The basin´s axis follows the direction SW-NE. Close to the city of Most, the open-pit mine of ČSA has been established. The working face proceeds towards the deposit´s marginal part on foothills of the Krušné hory slopes. Unfavourable geological conditions in this part complicate the coal extraction.

The contact of crystalline rocks of Krušné hory with the basin´s tertiary sediments is morphologically quite striking. Mountain slopes with a general gradient of 35-40^{o} /upto 70^{o} in the investigated area/ pass into the gently dipping plane of the basin´s sediments. The approaching of the working face to the foothills of mountain slopes is supposed to expose the slope up to its overall height of 800 m. Such an extensive interference with natural conditions will certainly cause a lot of problems, such as the slope stability, effect of open-pit mining on the water-flow conditions of Krušné hory, etc. Hydrogeological investigations have been carried out in the forefield of the open pit ČSA. Bore-holes were lined up into profiles, which proceed from the basin to the region of crystalline rocks. The scope of this survey was to establish the hydraulic parameters of water-bearing collectors and the variations of the groundwater level in connection with mining activities.

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS OF THE REGION

The forefield of the open pit ČSA and the slopes of Krušné hory belong to drainage areas of brooks Kundratický, Vesnický, and Šramnický. Water streams have their sources in the neighbourhood of the watershed in 850 m /above sea level/. On the foothills of the slopes, they discharge into the basin at the elevation of 310-330 m. The surface waters are here collected by an artificial channel and conducted to a water reservoir /see Fig. 1/. The purpose of this arrangement is to reduce the infiltration of water into quaternary sediments within the basin. The region of the tertiary basin is characterized by a relatively even plane with slow inclination towards south. In the direction to NW the terrain gradually ascends upwards. Mountain slopes are modelled by deeply cut valleys.

Both morphological units form structurally and lithologically different massifs. The mountains of Krušné hory are formed of crystalline rocks, type orthogneisses and granite-gneisses, penetrated by granites and basalts. Crystalline rocks continue in the SE direction to greater depths, forming the bedrock of the tertiary fill of the basin. Arenaceous and argillaceous sediments /age upper Cretaceous and Oligocene/

are deposited on the underlying kaolinized crystalline formations. These rocks occur in the form of denudation residues. Main fill of the basin consists of neogenic sediments mostly in the arenaceous-to-argilaceous development stages. The origin of the thick coal seam /average thickness of 25-30 m/ is attributed to Miocene. As to the area, most extensive are the quaternary sediments. In the region of Krušné hory, diluvial sediments are prevailing. At the foothills resp. at the outlet of valleys, proluvial deposits were formed in the form of dejection cones. These deposits continue as clayey gravels towards the centre of the basin. Tectonically, most important is the sub-mountain fault, which proceeds in the direction SW to NE. According to survey results, it concerns a large zone of faults in the neighbourhood of the margin of the crystalline rock massif. The region is faulted by former transverse faults, which predispose the course of mountain valleys. No significant fault zone could be found in the investigated region within the basin.

During this survey within the crystalline region, only the zone of shallow cycling of groundwater in quaternary sediments and upper gneiss zones has been investigated. The water infiltration depends directly on precipitations. The average permeability is very low, according to the filtration coefficient 10^{-7} - 10^{-8} m.s^{-1}. Crystalline rocks in the bedrock of the basin and in the mountain region are intensively kaolinized to greater depths. The hydrogeological position of this layer functions as an insulator. In the bedrock of the coal seam in the tertiary sediments a hydraulically uniform collector of underlying psammites was formed. This collector includes all permeable layers irrespective of their age. The overall permeability of the collector is very low, of the order of 10^{-7} m.s^{-1} and the abundances are small. High piezometric stress with the groundwater level affecting the elevation of the coal seam basis, is characteristical for this collector. From the excavation´s viewpoint, it is obvious that the stress must be relieved by drainage of the coal seam prior to the coal extraction.

The coal measures form an independent water-bearing collector. The permeability depends on the deposition depth and on the fissurized condition of the coal seam /7/. The infiltration of water takes place on the seam outcrops at the foothills of mountain slopes, or accross the proluvial sediments. The water infiltration is also possible through old mine openings, situated on the seam outcrops. The quaternary water-bearing collector on the Krušné hory slopes is characterized by low permeability, of the order of 10^{-7} - 10^{-6} m.s^{-1}. The permeability moderately increases from the morphologic boundary towards the basin, where it attains values of 2.10^{-4} m.s^{-1} /7/.

METHODS OF INVESTIGATION

The transmissivity coefficient is chosen for the comparison of results of hydrodynamic tests in wells and for hydrogeological evaluation of the investigated region. However, it proved suitable to express this coefficient in a simpler form, i.e. as a logarithmic comparative parameter - the number Y. This parameter is determined according to the relation:

$$Y = \log/N.q/, \qquad /1/$$

where q = specific capacity $/m^2.s^{-1}/$;

$N = 10^9$.

This comparative parameter for transmissivity can be practically determined during each pumping test, even without knowledge of the thickness of the water-bearing collector /4/.

The method of the natural radionuclide /1,2/ was applied, in the investigated territory, for the evaluation of displacements of groundwaters. The method is based on the observation of alterations of a natural radionuclide on selected sites in certain time series. The capacity of laboratories was sufficient for measurements of specific activities of tritium /3/, but it did not allow to effectuate correction measurements of carbon-14. Samples of natural waters were drawn during the years 1977-1979. Wells, where pumping tests were performed, were selected as basic sampling sites. The lines of wells followed the mountain brook valleys and their original course in the basin. Samples of waters were drawn also from the oozing sources from old mine drain adits "Natalie" and "Johanni" /Fig.1/. The progress of stripping operations negatively affected the sampling of water owing to progressive liquidation of wells and owing to the creation of conditions for the inflow of water from the surface; this was the case for e.g. wells No. 28 and 15. Sampling of water was always effectuated from the opened section in the water-bearing collector. The groundwater, which descends from the Krušné hory slopes into the basin, is generally drained towards SE. This natural mechanism of groundwater cycling can be expressed by means of a simplified water-flow model - "piston flow" - for final determination of the tritium age of water /5,6/.

DISCUSSION OF RESULTS

The transmissivity of quaternary deposits, expressed by the comparison parameter Y, is illustrated on Fig. 2. For the region of crystalline rocks, some data are lacking. In the drainage area of the Vesnický potok /brook/, the maximum value of 6.3 was determined on the well No. 19. This well hitted the proluvial gravels on the foothills of the slope.

The transmissivity progressively decreases, according to isolines, in the direction towards the centre of the basin. This alteration folows the original bed of the brook. The values of the parameter $Y > 6$ were found also in wells No. 207 and 211. It can be supposed, that the course of such alterations is identical also for old valleys beneath the mountain slopes. These facts modify the traditional opinions on increasing transmissivity towards the centre of the basin, within its whole extent. No closer relationships were revealed in the second water-bearing collector. Generally, the transmissivity of the upper part of crystalline rocks is lower than that of the underlying psammites.

The collector of underlying psammites is characterized by high piezometric stress /tension/ within the entire area. This stress is reduced by the drainage of the collector by means of wells from the surface. Results of drainage appear on individual wells in dependence of the distance of the well from the drainage system, resp. of the working face of the quarry. Wells No. 24 and 1 show, after 7 years, a reduction of the water level by 16 m, the well No. 26 - - 47 m, well No. 8 - 9.5 m, well No. 7 - 9 m, and well No. 34a - 8 m. The drainage effect of the open pit in the collector of underlying psammites appears also in wells in the forefield of the open pit, where there is no drainage system and where no stripping takes place. So, e.g., the well No. 207 did not show any changes in water level, well No. 211 - reduction by only 0.27 m, well No. 213 - reduction of 0.73 m, and in the well No. 214 the water level decreased by 1.6 m /Fig. 1/. The effects of drainage do not manifest themselves neither in the outcrop part of the basin /well No. 19/, nor in the crystalline rock area. Groundwater level decreases were not noticed in wells Nos. 13 and 14, which are situated in projections of the basin´s crystalline rocks. This confirms a good insulation function of kaolinized gneisses in the bedrock of the basin. The groundwater level in quaternary sediments follows the contours of the terrain´s surface with small variations. The drainage effects of the open-pit mine or those of the drainage systems appear, in the collector, to a very limited degree. This is caused by low transmissivity of sediments and the variability of their lithologic composition and thickness, which decreases in the direction towards the basin.

Results of measurements of specific activities of tritium in water samples are tabulated in tab. 1. The tritium values for individual years are calculated as averages from the measured water samples.

Measurements of specific activities of tritium resulted in several modifications of evaluation methods of measured values. From some wells, it was possible to draw samples from periods approaching the end of the pumping test. On the well No. 201, samples were drawn shortly after the start of pumping. Water from the pumping test in april 1977 had the activity of 70 T.U. In the water sample from the withdrawal in october 1977, the tritium activity increased to 99 T.U. During following sampling tests in 1978-79, the tritium activity dropped to the stable value of about 16 T.U. Similar differences were found also in wells No. 18, 19, and 37. However, in these wells the time lag between the water withdrawal /from the pumping test/ and operation tests was much longer. The mentioned alterations in activities confirm, that cleaning of wells by process waters, which originate mostly from surface streams, change the original isotopic composition of groundwater in the neighbourhood of wells. The surface and precipitaion /rain etc./ waters are generally characterized by high specific activity of tritium - about 120-150 T.U. Thesc values are much lower for groundwater - 15-30 T.U. It is interesting, that during a short-time pumping test it proved impossible to establish the original isotopic conditions within the collector. It results from these facts, that the representativity of water samples from single withdrawals is quite limited. It is therefore adequate, for terrains with low transmissivity, to confirm the measured tritium activities by repeated sampling.

The profile of the Kundratický brook begins in the crystalline area by wells Nos. 4, 5 and 6, which are situated in the inundation zone of the stream. Drilling was discontinued in weathered gneisses. The water in the well No. 4 has a definite dependence on the surface water, as proved by tritium activities. A longer retardation of level alterations of freatic water in comparison with those of water in the brook is observed in this hole. This is also reflected by lower levels of tritium activities in comparison with the surface water, which has an average value of 179 T.U. The well No. 5 is situated directly on the brook bank, but the freatic water does not exhibit any dependence on the water levelin the brook. Some differences in tritium activities are observed in samples from various depths. Water samples, drawn from underlying gneisses, have somewhat higher tritium activitics than those, drawn from the basis of the quaternary collector. It is interesting, that the difference between the values of tritium activities of freatic and surface waters is the same as at the well No. 4. The well No. 6 is situated at the border of valley fluvial accumulations, in the neighbourhood of outcrops of the tertiary measures. Conditions established at this well were practically identical with those at the well No. 5. The difference consists in generally lower total tritium activities. There is a certain isotopic inversion, because the groundwaters of geologically younger sediments are isotopically older than the groundwater from older crystalline rocks. The difference in tritium activities at this well is in good agreement with results of the pumping test from the upper part of the profile, where a lower transmissivity has been established. The progressive decrease of tritium activities in fluvial accumulations of the lower part of Kundratický brook confirms the reduction of transmissivity in the direction towards the basin, as it can be seen from wells No. 7a, 2, and 1. The values of tritium activities are in agreement with those found at the wells No. 4 and 5. In the area of wells No. 7a, 8, 8a and 2, only the infiltration of precipitation water makes themself felt, because the water of Kundratický brook was already diverted outside the basin. Low activities of tritium seem to be caused by the local development of quaternary sediments.

The second water-bearing collector was investigated only in the basin. The intact underlying crystalline rocks were not exposed by any bore-hole. According to results of the wells No. 8 and 1, it is evident, that the groundwater of underlying psammites represents the "old" water with the tritium age of 25 years. Even higher ages can be supposed. At the end of the year 1979, a contamination of water in the well No. 8 by inflow of isotopically "younger" water from the surface was due to inadequate procedures during these observations. Results of tritium measurements in the well No. 1 prove a good insulating function of underlying and overlying layers. In the well No. 8a, the tritium activities of water from the arenaceous positions of the strata series were observed. The average specific activity was 13 T.U., which anambiguously confirms the insulated position of the arenaceous collector with low transmissivity /Y = 4.5/. The constant level of groundwater supports this statement. At the well No. 2, the tritium activities of water from the overlying coal seam, which is considered an eventual future reserve were measured. Greater regional expansion of the area towards the outcrop region is reflected in higher values of tritium activities - 29 T.U.

The wells Nos. 17, 18 and 201 in the profile of Vesnický brook are situated in the region of crystalline rocks. The quaternary sediments and weathered gneisses were separated, in wells No. 17 and 18, for independent observations of water levels. The weathering thickness and the fractured condition of gneisses is quite high, because the near-by well No. 201 was terminated in the depth of 61 m /elevation 298.8 m above s.l./ without reaching the solid intact rock. The established tritium activities indicate a very slow motion of groundwater within the entire geological profile. Similar conditions are revealed by tritium analyses in water samples from wells No. 13 and 14. Higher tritium activities in the well No. 14 are probably caused by the inflow of water from the surface, due to the position of the hole in a morphological depression. Interesting is the position of the well No. 15, in which the flushed sediments of the marginal facies are entrapped in the bedrock of the strata series. The rocks are characterized by very low transmissivity, in spite of the fact that the tritium values point to quicker circulation of groundwaters. In the neighbourhood of this well, some earthwork has been realized in 1979, which evidently affected the surrounding rocks. These changes of terrain obviously caused a partial inflow of surface water into the well. The isotopic analyses of covering sediments in the basin reveal the relationship between the retention and infiltration of atmospheric precipitation water.

The water-bearing collector of underlying psammites was isotopically analysed in wells Nos. 21, 19, and 37. Flushed sediments were determinated in the well No. 37 at the border of the basin. A decrease of the groundwater level by 2.8 m was noted in this well. Such a decrease is connected with the near-by stripping operations. However, the isotopic analyses confirm a good sealing function of underlying rocks and overlying strata, even at long-time decrease of water level in the well. Similar results are obtained by tritium measurements of water samples from the well No. 21. The well No. 19 is situated at the mouth of the valley of Vesnický potok /brook/ into the basin. The well hitted not only the marginal flushed sediments, but also the coal seam /elevation 320 above s.l./. The well pair No. 19 and 19a revealed also the cross tectonics /7/. Tritium values in groundwater from the collector of underlying psammites differ in these wells, from tritium values of other wells in the basin. In this outcrop part of the region a quicker circulation of groundwater is supposed, caused by the arenaceous composition of the collector and by the cross tectonics. Some support for this opinion is found in measurements of water samples from water outlets of the drain adits Natalie and Johanni. The average specific activity of tritium in water is 71 T.U. and 53 T.U., resp. The adits drain off the mine waters from old workings, which were founded at the outcrops of the coal seam on the foothills of Krušné hory.

For comparison, during 1979, regular water sampling was carried out in the well line Nos. 231, 232, and 233 in the valley of the Šramnický brook /see Fig. No. 1/. First two wells belong to the crystalline rock region of Krušné hory. The well No. 232 found a breccia of failured zone of 81.7 m thickness. Regular measurements of water levels in wells show considerable variations due to natural alterations. The water level of underlying gneisses is in the well No. 231 by 3 m higher, than the level in deluvial deposits. The transmissivity of quaternary sediments is higher, in comparison with fissured gneisses. Isotopic analyses are in agreement with tests and observations at the well No. 231. In surroundings of the well No. 232, there is, according to the tritium activities, a very limited displacement of groundwater. That is to say, that the hydrodynamic test was made only in the upper part of the profile, upto 11 m. The resulting value of transmissivity distorts the interpretation of the cycling regime of groundwater on this site. Unlike that, the tritium measurement results agree with observations from the adit, which crossed the same faulted zone without water inflows /Fig. No. 1/. The well No. 233 revealed detritic proluvial sediments and a thick, flushing, coarse--grained sediment /46.3 m/. The pumping test was not made from the underlying psammites, but only from the overlying clayey strata measures. The isotopic water analyses reveal similar conditions of groundwater cycle as the surroundings of the well No. 19. The well No. 233 is situated on the slope at the mouth of the brook into the basin.

Basing upon the obtained results, the flow velocity of groundwater was calculated for the area of crystalline rocks. A simple equation for the determination of actual velocity in horizontal direction was applied to this purpose. The equation´s form is:

$$v_s = \frac{Q}{F.n} \quad /m.day^{-1}/ \qquad /2/$$

where Q = flow rate of groundwater $/m^3.day^{-1}/$,

F = cross profile area $/m^2/$,

n = effective porosity /estimate 0.05/.

The valley of the Vesnický brook was chosen from three disponible profiles, because there the surface waters do not affect the groundwater level in proluvial sediments and underlying gneisses. The profile of the valley does not change between the wells No. 17 and 18. The depth of the flow profile of groundwater is determinated according to drilling profiles, even if the intact gneisses were not reached. The value of the flow rate Q is taken from the pumping test at the lowest level reduction. The minima of specific capacities $/1.5 \times 10^{-5}\ m^2.s^{-1}/$ confirm that there occurred no water inflow from underlying rocks during the pumping test. The displacement time of groundwater to the distance of 140 m /between both wells/ is 16 - 20 years. Results of the isotopic analyses of water samples indicate the tritium age of 18 - 22 years for the same conditions. Owing to the fair agreement of results, obtained by two different methods, the water circulation in upper part of underlying gneisses and in proluvial sediments can generally be considered as very slow /see Table 2/.

CONCLUSIONS

The cycle of groundwater in connection with mining activities was investigated in the contact area of Krušné hory Mts. with the fore-field of the open pit mine ČSA, by the application of specific activities of tritium. Basing upon these results, completed by results of geological survey, folowing conclusions can be drawn:

- possibility of application of the natural radionuclide method in a deposit region with mining activities is confirmed;
- the model of the groundwater cycle in water-bearing collectors of quaternary sediments, underlying psammites, and of the upper part of underlying gneisses is rendered more precise;

- the presumption of the cross tectonics in mountain brook valleys is confirmed;
- the sealing tightness of the weathered zone of underlying gneisses in relation to the reduction of piezometric stress in underlying psammites, by their drainage, is established. The tritium analyses enable us to control, whether there were any unwanted inflows of water from other collectors. This information if important for the excavation of coal;
- in the profile of Vesnický brook, the displacement velocity of groundwater was calculated to 16-20 years according to regular observations. This is in good agrement with the established tritium age of groundwater /18-22 years/;
- as far as the methodics is concerned, the limited representativity of water samples during single sampling in terrains with low transmissivity was established. The contamination of the well surroundings by "younger" water is not safely eliminated by short-time pumping-off of water.

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Table 1

Well No	Water-bearing collector	Depth of sample drawing	Elevation of sampling m a.s.l	Parameter Y	Specific activities of tritium average		
					1977 T.U.	1978 T.U.	1979 T.U.
Profile of the brook Kundratický							
4	Quat.	11	376,29	5,54	98	108	89
	Cry.r.	22	365,29				85
5	Quat.	6	343,11	4,7	87	68	86
	Cry.r.	26,5	322,61		104	77	97
6	Quat.	9,5	322,59	4,8	26	30	35
	Cry.r.	26	306,09	5,2	43	44	42
7a	Quat.	4,5	302,24	4,5	102	66	61
8	Quat.	3,5	293,83		108	71	
	und.ps.	154	143,56	5,2	9	17	35
8a	Quat.	4	293,81		77	81	73
2	Quat.	3	290,04	4,4	79	65	81
1	Quat.	3,5	287,34	4,9	18	17	19
	und.ps.	150	140,84	5,1	17	25	5
12	und.ps.			2,4			
32	Quat.			3,9			
9	Quat.			4,2			
22	Quat			6,3			
23	Quat			4,6			

30	Quat.			5,3			
25	Quat.			5,9			
Profile of the brook Vesnický							
17	Quat.	3,5	397,84		6	20	11
	Cry.r.	16	385,34	4,2	25	17	14
	Cry.r.	25	376,34				20
18	Quat.	3,5	372,94	5,1	16	21	30
	Cry.r.	14	362,44	4,1			32
	Cry.r.	21	355,44		25	25	28
201	Cry.r.	49	310,85	3,4	99	17	15
19	Quat.			6,3			
	und.ps.	40	306,91	4,6	65	79	68
21	Quat.	3	292,09	5,7	97	64	
	und.ps.	89	206,46	5,3	38	21	31
28	Quat.	11	271,28	5,2		78	
	und.ps.			3,7			
34a	Quat.			5,5			
27	Quat.			3,6			
26	und.ps.			2,6			
13	Cry.r.	11,5	311,08	3,8	12	16	24
14	Cry.r.	16	291,83	4	85	47	47
15	Cry	24	267,29	2,8			78

37	und.ps.	20	282,55	4,8		41	35
	und.ps.	30	272,55				26
16	und.ps.			5,6			
24	Quat.			5,7			
	und.ps.			3,7			
202	Quat.			4,2			
	und.ps.			4,6			
207	Quat.			6,1			
	und.ps.			5,3			
211	Quat.			6,2			
	und.ps.			4,9			
213	und.ps.			4,3			
214	Quat.			4,2			
	und.ps.			5,4			
Profile of the brook Šramnický							
231	Quat.	4	373,22				12
	Cry.r.	25	351,22	3,8			10
232	kv	49	294,4	5			7
	Quat.	69	274,4				12
233	Quat.	5	306,96	5,1			81
	und.ps.	90	221,96	3,3			92
drain adit Natalie					75	54	75
drain adit Johani					46	42	56

Table 2

Well No	Water-bearing profile		Q	Flow rate	
	width m	height m	$m^3.day^{-1}$	$m.day^{-1}$	$m.year^{-1}$
17	50	29	1,73	0,024	8,7
18	40	27	1,3	0,0192	7,-

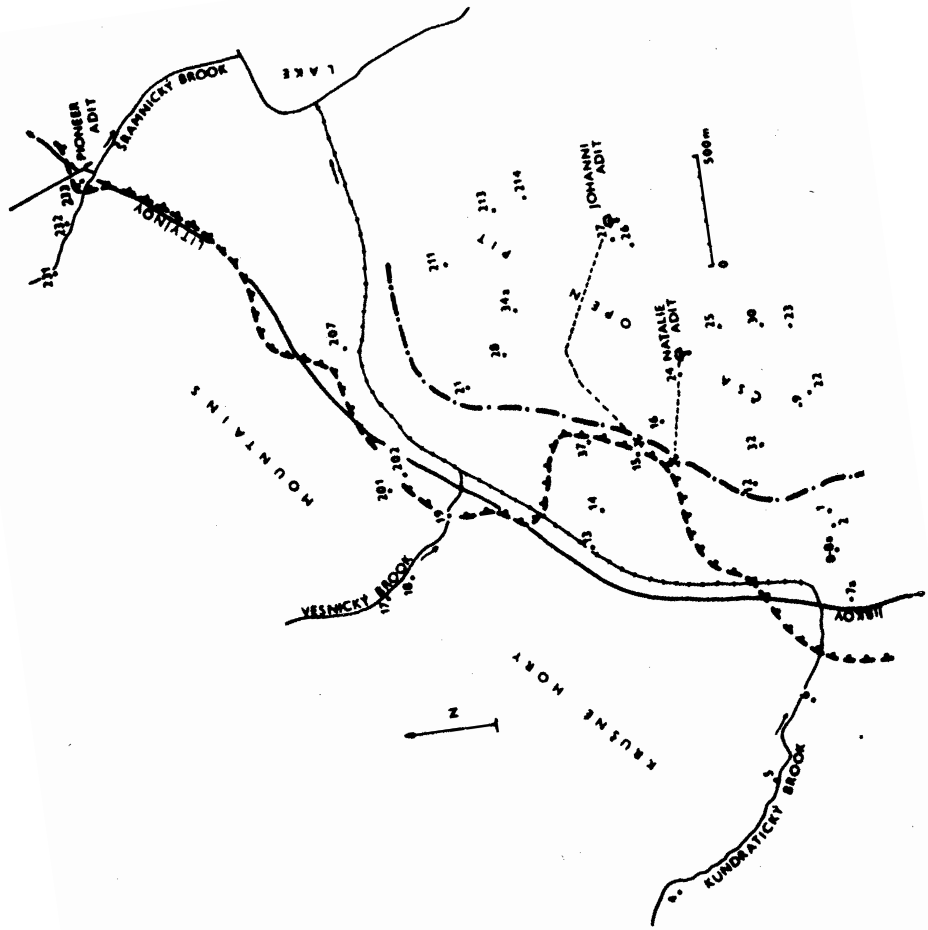
List of Figures

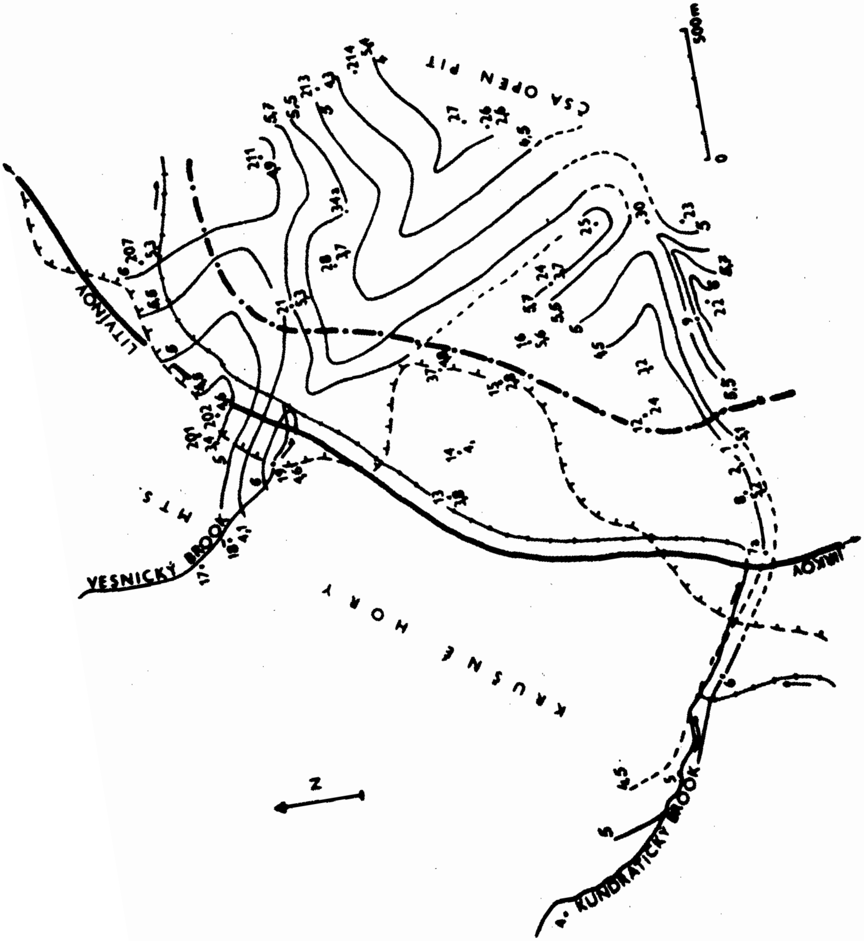
Figure 1: Situation of observing wells in the fore-field of the open pit mine ČSA

- observing well
- outcrop of the coal seam
- collecting channel for surface waters
- stripping edge of the open-pit mine ČSA /1980/

Figure 2: Map of iso-lines of the comparative parameter Y in the quaternary water-bearing collector

- iso-line of the parameter Y




ČSA OPEN PIT
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