The assessment of the fracture zone of Valias coal mine in Albania, using the single well point dilution method of a radioactive tracer

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Abstract: The vertical profile of groundwater flow velocity determined in four wells by the point dilution of a radioactive tracer was used for the identification of the thickness of the intensive fractured zone developed in Valias coal mine in Albania. This was necessary for the protection of the mine from the of overlaid gravelly aquifer groundwater.

Key words: Point dilution method of a radioactive tracer, groundwater Darcy velocity, coal mining, rocks deformation zones, zone of intensive fracture.

INTRODUCTION

The mining under surface or under the groundwater bodies implies often the determination of the thickness of the intensive fractured zone of the rocks above the caving level. Knowing the thickness of this zone, the size of the protective pillar of the mine from the surface or groundwater bodies could be determined. However the solution of the problem is complicated by the variety of the factors influencing on the formation of the fracture zones like: geologic and tectonic conditions, physical-mechanical properties of the rocks, mining technology, the slope and the thickness of the mined layers, as well as their depth below ground surface, the presence or the lack of impermeable layers between surface or underground water bodies and the mining horizon, etc.
The often used analogy or empirical solution described by Chian (1973), Gvircman et al. (1985) and VNIMI (1957) may lead to over estimation or to under estimation of the thickness of the protective pillar, with serious consequences on the efficiency and on the security of the mine.
In Valias coal mine this parameter is determined experimentally, applying two independent methods; water injection in some boreholes and the single well point dilution method of a radioactive tracer. In the present paper is described the application of radioactive tracer techniques and how the measured Darcy flow velocity is applied for dimensioning the protective pillar in Valias coal mine.

GEOLOGY AND THE PROBLEM OF VALIAS COAL MINE

Valias coal mine is located in Tirana plain, about 15 km northwest to Tirana City. The coal layers belong to Upper Miocene age filling the Tirana syncline. As described by Pano & Zoto (1985) the lithology section is constituted manly by clay (44 %) and siltstone (42 %) and less by sandstone (7 %) and by coal layers and coal slates (7 %). The maximal thickness of coal layers is about 1.50 m. The rock layers are differently intercalated and deep to the west by angles 10-12°, and to northwest by angles 3-4°. Above the Upper Miocene deposits are placed Quaternary deposits represented of a gravel layer about 30 m thick covered by silt and clay sediments.

The Tortonian deposits are characterized as a poor aquifer; the mean coefficient of permeability of sandstone layers is about 0.04 to 0.08 m/day and the mean transmissivity of rocks is about 2 to 3.5 m²/day. The gravel layer is an abundant aquifer, the coefficient of permeability usually varies from 10 to 80 m/day and the transmissivity varies from 350 to 3000 m²/day, (Tafilaj, 1968).

In Valias coal mine is applied the longwall exploitation along the coal bad extension causing the total roof falling. The goafs created by the coal exploitation temporary were hold with metallic props. After removing of metallic props the roof starts to bend and later the roof rocks begin to failure. Zoto (1997) described that the rock movement is transmitted to the upper rock massive resulting in the formation of a so-called funnel of deformations. Three rock massive movement zones are distinguished inside the deformation funnel; caved zone (thickness Hc), zone of intensive fractures (thickness Hf) and zone of plastic deformations as which in Figure 1. The rock deformations are transmitted up to the ground surface where the maximal subsidence Hs, in the center of deformation funnel is about 2 m.

As seen in Figure 1, if the zone of intensive fractures riches the gravel aquifer, the groundwater was expected to be drained in the mine, compromising the normal work of the mine if not permanent loss of important coal resources. Therefore to prevent such undesirable consequences, the thickness of zone of intensive fractures was absolutely necessary.

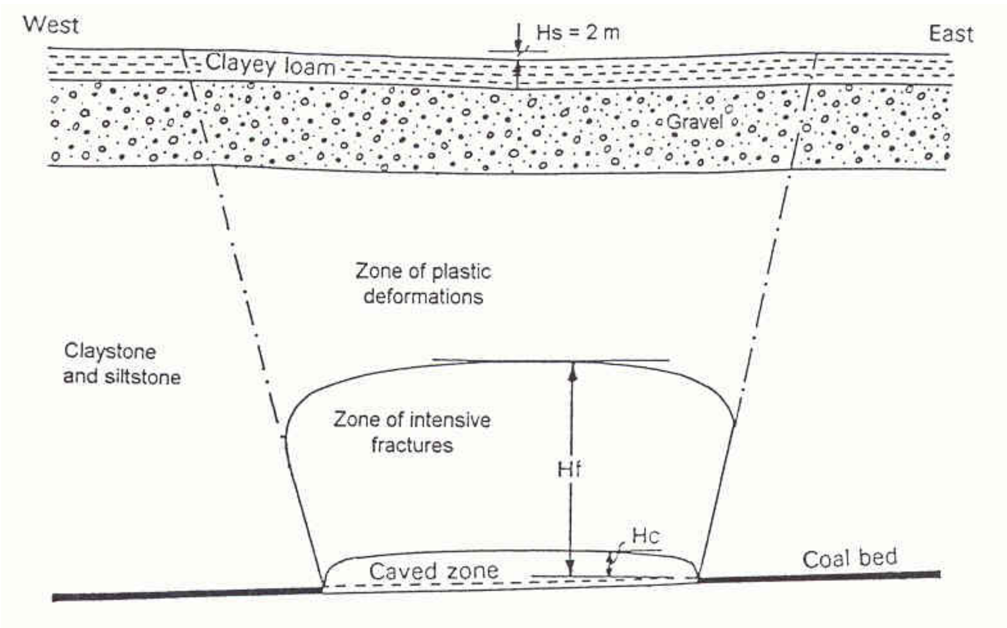

Figure 1. Schematic view of rock deformations zones in Valias coal mine

METHODOLOGICAL APPROACH

It was assumed that the secondary porosity of the rocks of the zone of intensive fractures caused by the mining should be much higher than the primary natural porosity. The same was assumed to happen also with the groundwater filtration velocity of the rock body effected by intensive fracturing. However the direct and accurate measurement of the primary and of secondary porosity is very tiresome or practically impossible. To aim this problem, two indirect methods are applied independently on some specially constructed boreholes; water injection and single well point dilution method of a radioactive tracer. By the water injection realized according to a special schema described by Pano & Zoto (1985), the fracturing intensity is evaluated by measuring the volume of infiltrated water. The single well point dilution method of a radioactive tracer is applied for measuring the groundwater Darcy flow velocity, which as known is a macro-porosity dependent parameter.
The aim of the application of the radioactive method was the qualitative evaluation of the primary and secondary porosity of rocks at different times and at different depths within a certain geological area. The experiments are organized according the following schema:

a) Estimation of the groundwater flow velocity, both, inside and outside the area of deformation funnel, expecting higher groundwater flow velocity inside then outside the area of deformation funnel;
b) Estimation of groundwater flow velocity at different times in the same well, when it was outside the deformation funnel and after a certain time when it was included inside this funnel. In the second case the estimated groundwater flow velocity was expected to be higher.
c) The groundwater flow velocity inside the deformation funnel was expected to be higher in the depth coinciding with the zone of intensive fractures than in the zone of plastic deformation of rocks.

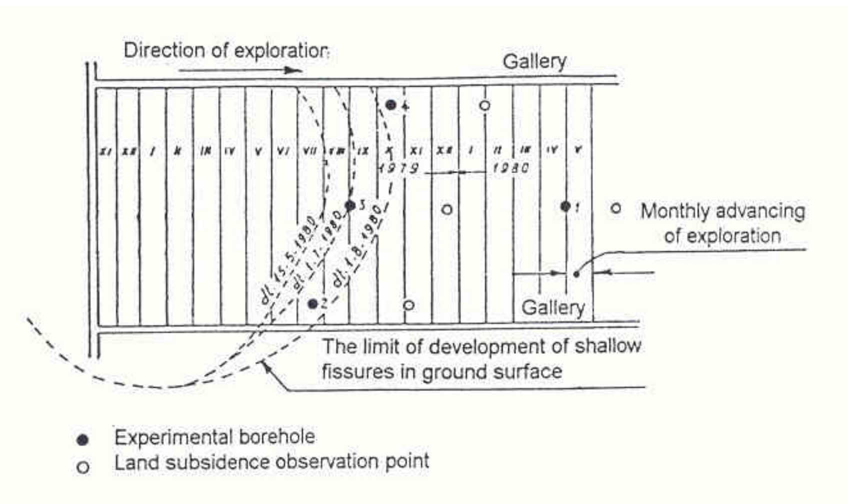

Figure 2. Location of the experimental boreholes

In Figure 2 is shown the experimental site constituted of four boreholes depth 117-138m: Well 1 was located at the longwall axes area but outside the rock's movement zone; three wells were located inside the rock movement zone, one of them on the longwall axes area and the two remaining wells were located on both sides of longwall periphery area.
Borehole No 1 was located 70 m far from the longwall mining front-line, while the remaining boreholes No. 2, 3 and 4 were located about 30 m behind this line (inside the mining area). The boreholes were suspended about 10 m above the mined coal layer. The tapped by the boreholes gravelly aquifer was isolated. The diameter of borehole casing was 108 mm and most of section of the drilled Upper Miocene coal bearing rock massive was screened.

DETERMINATION OF THE FILTRATION VELOCITY BY SINGLE WELL POINT DILUTION METHOD OF A RADIOACTIVE TRACER

Ogolvi (1958) was the first to found the solution existing between the dilution velocity of a tracer injected in a well and the groundwater filtration velocity which afterwards was applied for a radioactive tracer by Drost at al., 1968, Drost & Klotz, 1983, Halevy et al., 1966, Klotz et al., 1979:

$$V_f = \frac{V}{\alpha F t} \ln \frac{C}{C_o}$$

Where: V_f = groundwater filtration velocity; V = volume of labeled water column; α = coefficient of distortion of the flow lines by the presence of the filter tub; F = area of the section perpendicular to the groundwater flow direction; C = concentration of the labeled water column at time t = t; C_o = concentration of the labeled water column at t = t_o.
The coefficient α depends on the diameter of filter tube, on the gravel pack thickness, and also on the permeability of the filter tube and of the gravel pack. If the these parameters are known the coefficient α can be estimated using the procedure described by Drost et al., 1968, Drost & Neemaier, 1974 and Klotz et al., 1979. For Valias experimental wells the value of coefficient α resulted 2.04 to 2.10 (Ahmataj 1981, Tafilaj et al., 1980).
As already known some requirements should be respected for the successful application of this method: the tracer is injected in a water volume inside the borehole which is delimited by two packers in order to avoid the vertical transport of the tracer. If the vertical in-well flows are negligible the measurement can be done with necessary accuracy without packers (Boanza et al., 1970, Tazioli 1973). This was the case of Valias experiment because even relative values of the groundwater filtration velocity prove to be useful for correct interpretation.
As a tracer is used iodine-131 as NaI solution and the activity used for each injection was 13 to 150 μCi. The radioactive tracer was injected with a mechanical syringe applied by Tazioli (1973). For radioactivity measurement digital analog scintillation detector is used. The radioactivity measurements are performed at different time

intervals, and on every meter from the basement of the gravelly aquifer to the borehole bottom. Before the injection natural gamma activity of the rocks penetrated by the borehole is measured.

ELABORATION OF DATA AND RESULTS

The measurements corrected for the natural radioactivity of the rocks and for the radioactivity decay during the time interval from the injection to the measurement are presented graphically enabling to find the intervals for the evaluation of the groundwater velocity. Figure 3 shows the variation of tracer activity in well No 3. In this borehole two injections are performed at depths 75 m and 101 m below the ground surface (bgs). During the firs 24 hours after the injection the radioactive clod concentrated initially at the depth interval 75-80 m by vertical flow currents was removed to the depth 85 m. Afterwards only dilution without vertical currents was observed. Making the balance of the radioactivity for different selected depth intervals the groundwater filtration velocity was estimated by the decreasing rate of the tracer concentrations. In Table 1 is shown the chronology and the organization of the tracing experiments performed in Valias coal mine during the period January-May 1980. The results of estimation of the groundwater flow velocity gained at three boreholes are shown in Figure 4.

Borehole 1

The *first experiment* performed in borehole 1 aimed to estimate the groundwater flow at natural conditions; prior that the rock massive suffers the deformations resulted by the coal mining. The gained results afterwards are compared with the velocity data measured at other wells located inside the area of deformations and with the velocity data measured in the borehole No 1 when it was included in the deformation area. The estimated groundwater velocity resulted from 0.2 to 0.6 cm/day, (in average 0.3 m/day), while the limit of the method according to Bahrens (1983) is about 0.5 cm/day.
When the *second experiment* is performed, in February 22, 1980 the borehole was nearer to mining front but still was not included in intensively deformation zone. At depth interval 95-104 m bgs the flow velocity resulted 5 cm/day.

Table 1. Chronology and the organization of the experiments

Borehole number	Dates of the experiments	Number of injections	Depth of injection, m bgs	Measured time intervals
1	January 5 February 22 April 25 May 15	4 1 1 1	45, 60, 70, 102 112 98 74	5 4 2 3
2	February 18 April 25 April 27	2 1 1	81, 99 95 70	11 2 6
3	April 24	2	75, 101	6
4	April 24	2	70, 90	5

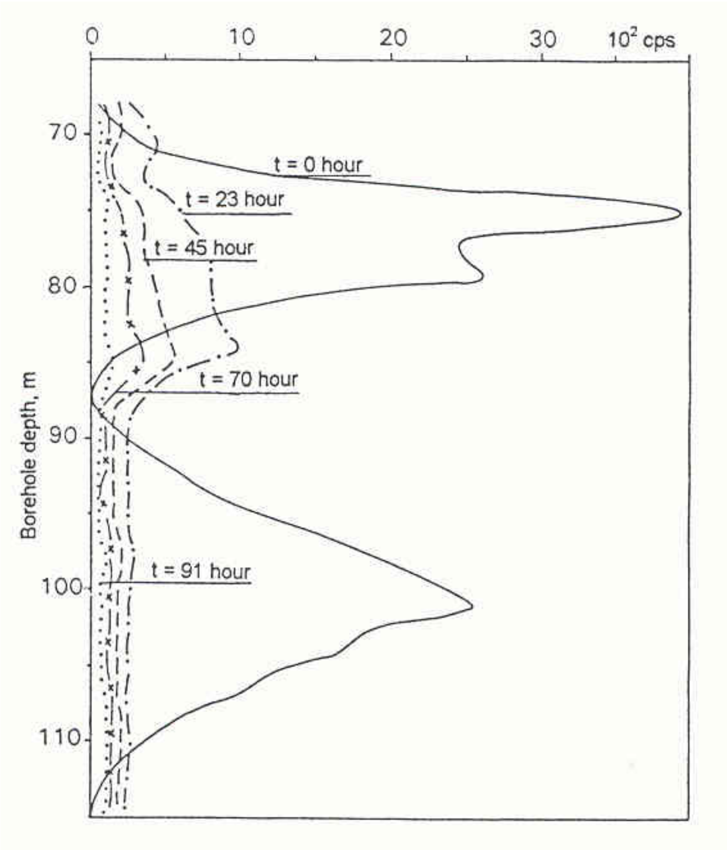

Figure 3. Variation of tracer activity in borehole No 3

The *third experiment* is performed on May 25, 1980. At that time the borehole 1 was included inside the area of intensive deformations; the groundwater level in the well was lowered about 10 m, while the natural groundwater level outside the rocks deformation area was practically the same as in January. The estimated groundwater filtration velocity at the depth interval 90-113 m resulted 17.5 cm/day, which is distinctly higher then the velocity measured at undisturbed natural conditions.

The aim of the *fourth experiment* performed on May 15, 1980 was to estimate the groundwater filtration velocity at borehole depth interval above 90 m bgs not detected by the former experiments. By the experiment was detected the presence of intensive downward vertical water currents with the rate about 0.2 to 0.4 l/min, which totally disappeared at 90 m bgs. The fact indicates the presence of an intensive horizontal groundwater flow at this depth. A rough estimation of the horizontal filtration velocity resulted 5.3 cm/day.

Borehole 2

This borehole from the very beginning of the experiments was inside the zone of intensive deformations of rocks.

By the *first experiment* performed on February 18, 1980 the estimated groundwater filtration velocity along the tested depth interval 70-125 m bgs resulted about 2 to 4 cm/day.

During the *second experiment* realized on April 25, 1980 only one injection at depth 95 m bgs is performed. After 24 hours the radioactive tracer was practically disappeared and the estimated groundwater filtration velocity resulted to be 12.5 m/day.

The aim of the *third experiment* performed on April 27, 1980 was to estimate the groundwater filtration velocity at borehole depth interval above 90 m bgs, not detected by the former experiments. The injection was realized at the depth 70 m bgs and the estimated groundwater flow velocity resulted 2.5 cm/day.

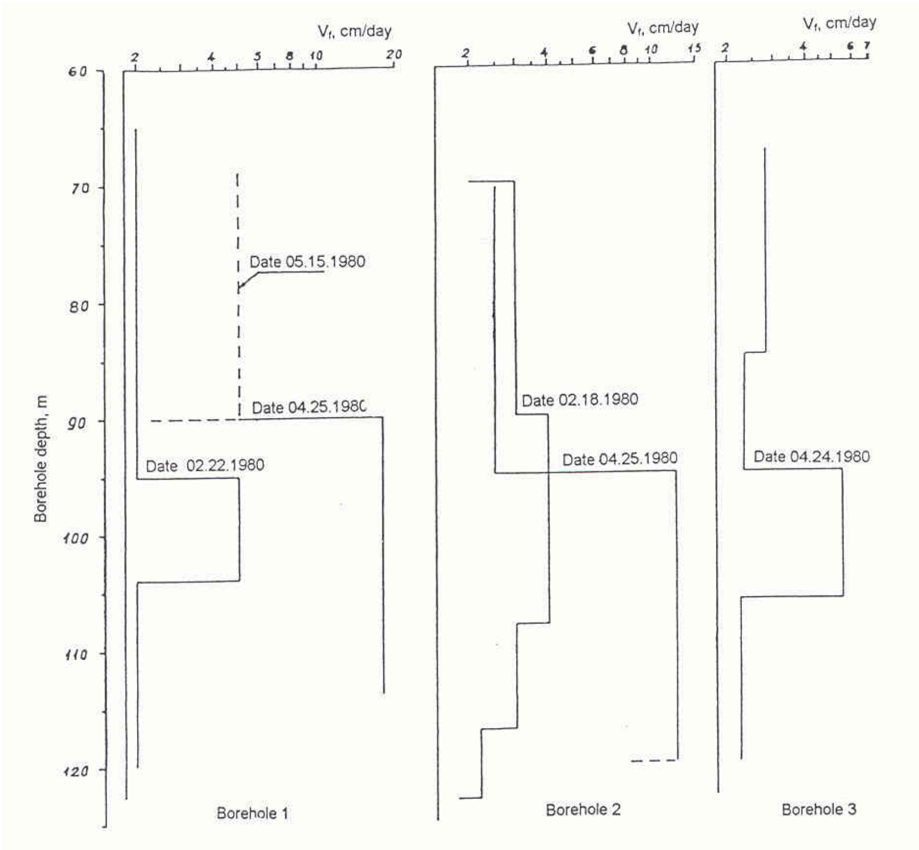

Figure 4. The profiles of estimated groundwater flow velocity of borehole No 1, 2 and 3

Borehole 3 and 4

Though the borehole 3 is located in the center of the deformation zone, the groundwater filtration velocity resulted relatively low regarding to the expectations, but distinctly higher than the velocity measured in undisturbed rock massive. The maximal groundwater flow velocity measured at the depth interval 95-106 m resulted 5.5 cm/day. This experiment was performed about 20 days after the water injection experiment.

The velocity profile of Borehole 4 resulted even more flat than this of borehole 3; at the depth interval 59-103 m the groundwater filtration velocity resulted 2 cm/day. The time span between the water injection experiment and the radioactive tracer experiment was 24 days for borehole 3 and 4 days for borehole 4.

"Unexpected" low groundwater filtration velocity measured at boreholes 3 and 4 is explained with the small time span between the precursor water injection experiment and the successive radioactive tracer experiment. The observations verify that the results of point dilution experiment of a radioactive tracer are likely more indicative when are realized not less than about 40 days after the water injection experiments

Summarizing the results of the tracer experiments presented in Figure 4, the top of the zone of intensive fractures is identified at the depth about 95 bgs and the thickness of the intensively fractured zone created in the rock massive above the caved coal layer in Valias coal mine resulted about 50 m. As a consequence the thickness of the protection pillar was determined about 60. The results obtained by the single well point dilution method of a radioactive tracer are in a very good harmony with the results obtained by the water injection method (Pano & Zoto, 1985). In Figure 5 is shown the water loss profile of the injected water in borehole 2. As can be seen the top of the intensive water losses zone, which is identified with the top of intensive fracture zone, is located at the depth 95 m bgs.

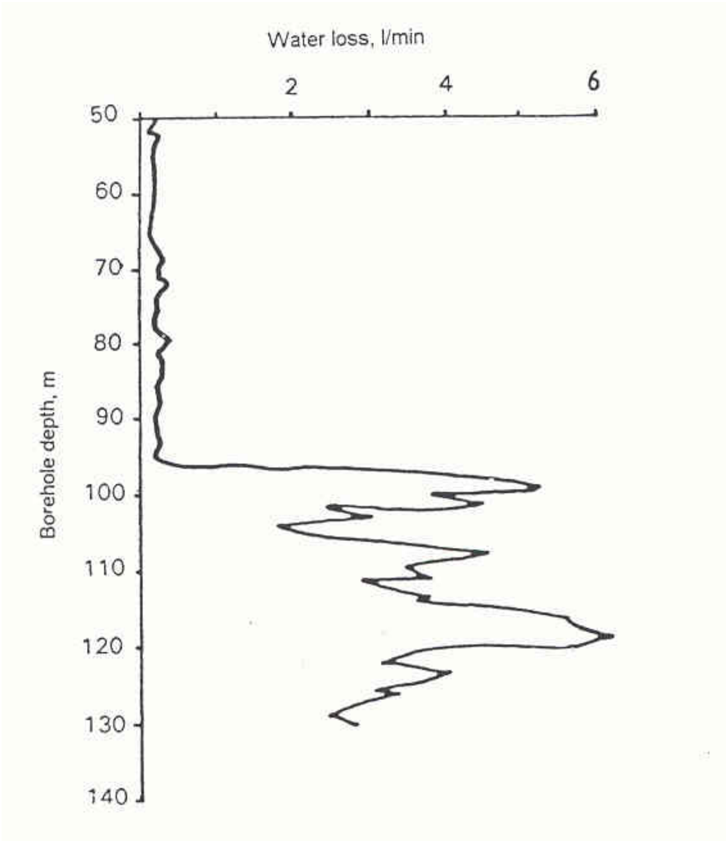

Figure 5. The loss of injected water in borehole No. 2

CONCLUSIONS

The point dilution method of a radioactive tracer may provide an independent approach for solving the problem of the identification the thickness of the zone of intensive fractures developed above the mines applying the total roof falling method of caving. The application of this method in conjunction with other methods, as for example water injection method, is likely to be most productive.

When the point dilution method of a radioactive tracer has to be applied in the same wells after the water injection, an appropriate time span of at least about 40 days between them is indispensable.
In Valias coal mine the top of the intensively fractured zone was determined at the depth about 95 m below the ground surface and the thickness of the zone of intensive fractures resulted to be about 50 m. From this the thickness of the protection pillar was accepted to be 60 m being in the safe side.

Acknowledgements

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