INVESTIGATION OF THE ORIGIN OF THE WATER DISCHARGING AT THE REOCIN MINE USING ISOTOPE TECHNIQUES

A. PLATA-BEDMAR*
Centro de Estudios y Experimentación
de Obras Públicas,
Ministerio de Obras Públicas,
Madrid, Spain

Abstract

INVESTIGATION OF THE ORIGIN OF THE WATER DISCHARGING AT THE REOCIN MINE USING ISOTOPE TECHNIQUES.

The Reocín Mine is the most important zinc mine in Spain. Underground exploitation is carried out from galleries situated in a calcareous formation of Gargasian age. The depths of these galleries range from 250 to 340 metres. Drainage of the mine requires the pumping of about 1200 litres of water per second with an energy consumption of about 50×10^6 kW·h/a. The water emerges in the form of a concentrated flow through a fracture in the calcareous rock. The origin of this water has been investigated using environmental (^3H, ^2H and ^{18}O) and artificial (^3H and ^{131}I) isotopes. The results obtained have shown that about 72% of the mine drainage flow comes from the Saja River, which crosses the same geological formation at a distance of about 4 km from the mine. The infiltration zone was identified at a point along the river. Complementary information has also been obtained on the transit time of the water flowing from the river to the mine, the average capacity of the underground reservoir and the dispersivity of the groundwater flow.

1. INTRODUCTION

The Reocín zinc mine is located at Torrelavega near the northern coast of Spain (Fig. 1). Underground exploitation is carried out from deep galleries situated at depths of 150 and 240 metres below sea level. A continuous flow of about 1200 L/s emerges at the deepest gallery and has to be pumped out from an elevation difference of 340 metres. This amount of water is about 60 times the weight of the extracted mineral and the pumping costs are also high, approximately one-third of the total mine exploitation costs. On the other hand, a permanent hazard exists of increasing

* Present address: Isotope Hydrology Section, Division of Physical and Chemical Sciences, International Atomic Energy Agency, Vienna.

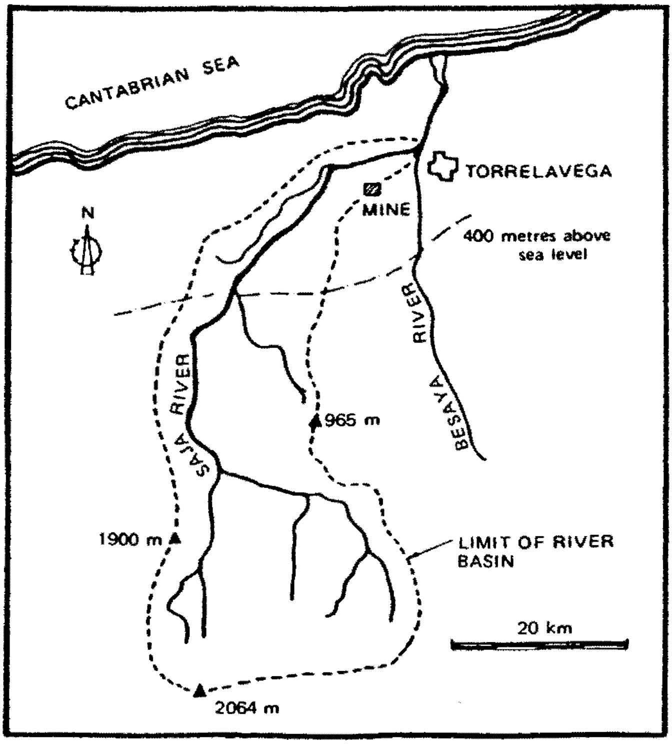

FIG. 1. Location of the Reocín Mine and the Saja River Basin.

the water drainage beyond the capacity of the installed pumping system during mining, which, obviously, could have very serious consequences.

A great deal of work has been done over the last 7 years to obtain information on the origin of the water [1–4]. Local precipitation and infiltration at the beds of the Saja and Besaya Rivers are the possible sources of the mine water. The results which have been obtained to date are contradictory. López-Vera et al. [2] concluded that these rivers should be responsible for most of the water emerging in the mine. This hypothesis was based on the water balance of the local aquifers as well as on the chemical composition of the water. In contrast, Fernández-Rubio [3] estimated, more recently, that about 60% of the water originates from local precipitation. The author came to this conclusion through precise evaluation of the total area covered by the local dolines, which amounts to about 20 km^2. He assumed that all the water infiltration taking place at these dolines is drained towards the mine.

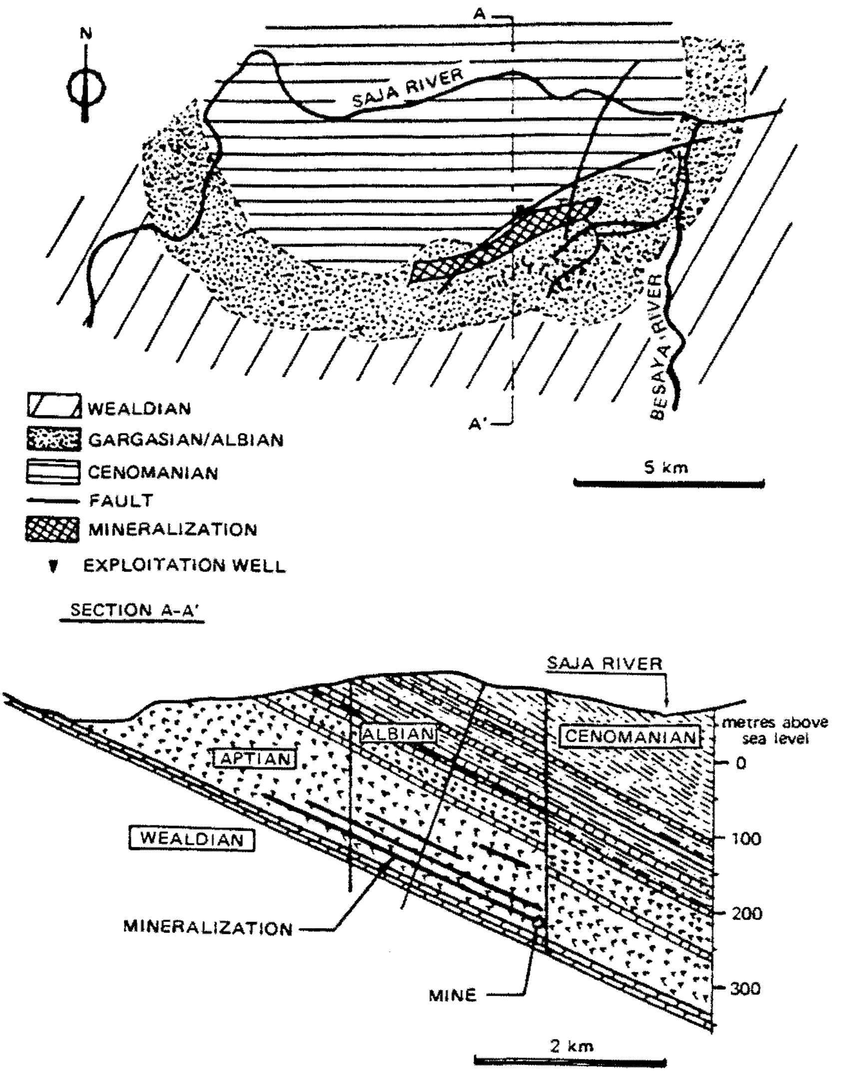

FIG. 2. Geology of the area.

2. HYDROGEOLOGICAL CONSIDERATIONS

The geological characteristics of the different formations are shown in Fig. 2. The mineral veins are located in a limestone and dolomite formation of Gargasian (Upper Aptian) age, with a thickness of about 200 metres. The impermeable substratum corresponds to red clays of Wealdian age. The Albian and Cenomanian formations, which overlie the Gargasian materials, are formed by a sequence of pervious and impervious strata of limestone, marls and detritic materials. The average vertical permeability of such materials could be very low.

The Gargasian outcrop describes a more or less circular band of about 2 km in width, which is crossed by the Saja and Besaya Rivers. The Lower Aptian (Bedoulian) has a thickness between 30 and 70 metres and can be considered as an aquitard.

Three different families of faults have been identified at the site of the mine and each has a slip which reaches a value of up to 150 metres. These faults may play an important role in the transport of groundwater towards the mine. In fact, karstification of the Gargasian dolomites and limestones at the level of the mine galleries is very low, or non-existent.

The morphology of the surface shows the existence of a well developed drainage system formed, basically, by abundant funnel shaped dolines of variable size. One of these dolines has a surface of about 1.6 km^2 and presents a well defined sinkhole for infiltration of the water.

Further, the local average precipitation is 1314 mm/a and the estimated evapotranspiration is about 750 mm/a.

3. EXPERIMENTAL WORK

The following isotope techniques have been used to obtain information on the origin of the water flowing into the mine:

(1) Measurement of thermonuclear tritium
(2) Measurement of the stable isotopes ^{2}H and ^{18}O
(3) Determination of the flow rate in the Saja River using ^{131}I as the tracer
(4) An interconnection experiment between the Saja River and the mine drainage flow using artificial tritium as the tracer.

The results obtained and their interpretation are presented in the following sections.

3.1. Thermonuclear tritium

Environmental tritium was analysed in mine water samples taken at different times. The tritium concentrations obtained for all these water samples are very similar; the average value is 19.6 $\pm$ 0.8 (σ deviation) tritium units (TU). Evaluation of the thermonuclear tritium concentration for local precipitation was made on the basis of the existing information for other stations in Spain (Madrid, Pontevedra, Barcelona and Malaga), where tritium measurements have been carried out with variable regularity since 1967. The results revealed that this tritium concentration may well correspond to water which was infiltrated during the last 2 or 3 years (1983). The low salinity of the mine drainage water (250 μS/cm of conductivity) also suggests a short residence time for the water in the underground system. In contrast, two old springs with negligible flow rates that exist on the other extreme of the same gallery presented much lower tritium concentrations and a conductivity higher than 2000 μS/cm.

3.2. Stable isotopes

The results of the stable isotopes ^2H and ^{18}O in water samples collected from the mine drainage flow, the Saja River and local springs and wells are shown in Tables I–III. The springs and wells are located in the area surrounding the mine and represent the isotope composition of local precipitation. Their elevations vary between 200 and 400 metres above sea level, so that a negligible altitude effect can be accepted for this water.

The tables give the individual δ value for each group of data. The last rows show the contribution of the Saja River to the mine drainage flow calculated by the following equation

$$f \cdot \delta_s + (1-f)\delta_G = \delta_M$$

where f is the fraction of water emerging from the Saja River and δ_s, δ_G and δ_M are the δ values for the Saja River, local groundwater and mine drainage flow, respectively.

In general, the average stable isotope compositions of the different groups of water samples show that the δ values for the mine water are much closer to those of the Saja River than to those of local precipitation. This means that the contribution of the Saja River to the mine discharge must be more important than the contribution of local precipitation. In contrast, the two old springs mentioned in Section 3.1 have δ values that match those of local precipitation (Table II).

The difference in isotopic composition between the Saja River and local precipitation is explained by the fact that the river carries water emerging mainly from the Cantabric Cordillera, which has an average elevation that is much higher than the elevation of the mine area (see Fig. 1). Obviously, we can expect that the average elevation of the precipitation which contributes to the river discharge must vary periodically over the course of the year in the sense of being higher during winter and especially during the snowmelt period. Unfortunately, it was not possible to carry out a detailed study of the periodic variations in the δ values. The only available information is given in Fig. 3 and corresponds to the time distribution of the $\delta^{18}O$ values given in Table III. The lines plotted for the Saja River in this figure represent the δ values for composite water samples prepared from individual samples

TABLE I. $\delta^{18}O$ VALUES OF WATER SAMPLES COLLECTED BETWEEN SEPTEMBER AND NOVEMBER 1982 (in ‰)

Local groundwater	Saja River	Mine water	
		Old springs	Filtration
−6.3/−7.1	−7.9	−6.9	−7.8
−6.4/−7.5	−7.6	−6.8	−7.6
−6.5/−6.5	−7.9		−7.9
−6.8/−6.4	−7.9		−8.0
−7.0/−6.3			−8.2
−6.4/−5.8			−7.7
−6.5/−6.9			−7.8
−6.9/−6.9			−8.2
			−7.7
−6.64	−7.83	−6.85	−7.88
Contribution of the Saja River ~100%			

TABLE II. ISOTOPIC COMPOSITION OF WATER SAMPLES COLLECTED BETWEEN JANUARY 1984 AND MARCH 1985 (in ‰)

Local groundwater		Saja River		Mine filtration	
δD	$\delta^{18}O$	δD	$\delta^{18}O$	δD	$\delta^{18}O$
−34.7	−6.5	−48.4	−9.3	−43.1	−8.6
−34.1	−6.5	−45.9	−8.6	−43.1	−8.1
−36.0	−6.5	−46.6	−9.3	−44.2	−8.2
−33.1	−6.1	−48.9	−9.8	−45.2	−8.6
−35.4	−6.3	−47.8	−9.2	−44.9	−8.4
−36.5	−6.6	−43.5	−8.4		
−35.1	−6.3	−49.2	−9.2		
−35.7	−6.3	−48.0	−9.0		
−33.3	−6.0	−47.7	−8.8		
−36.4	−6.0				
−33.1	−5.9				
−34.9	−6.1				
−34.9	−6.26	−47.3	−9.11	−44.1	−8.38
Contribution of the Saja River				With δD = 74.2% With $\delta^{18}O$ = 74.4%	

TABLE III. ISOTOPIC COMPOSITION OF WATER SAMPLES COLLECTED BETWEEN NOVEMBER 1984 AND SEPTEMBER 1985 (in ‰)

Local groundwater		Saja River		Mine filtration	
δD	$\delta^{18}O$	δD	$\delta^{18}O$	δD	$\delta^{18}O$
−32.6	−5.69	−50.1	−7.59	−40.4	−6.75
−31.4	−5.69	−47.7	−7.62	−40.0	−6.80
−31.5	−5.42	−43.9	−7.26	−42.2	−6.99
−34.9	−5.71	−41.7	−7.04	−41.2	−6.89
−29.1	−5.61			−41.9	−7.0
−31.9	−5.62	−45.8	−7.38	−41.1	−6.89
Contribution of the Saja River				With δD = 66.2% With $\delta^{18}O$ = 72.2%	

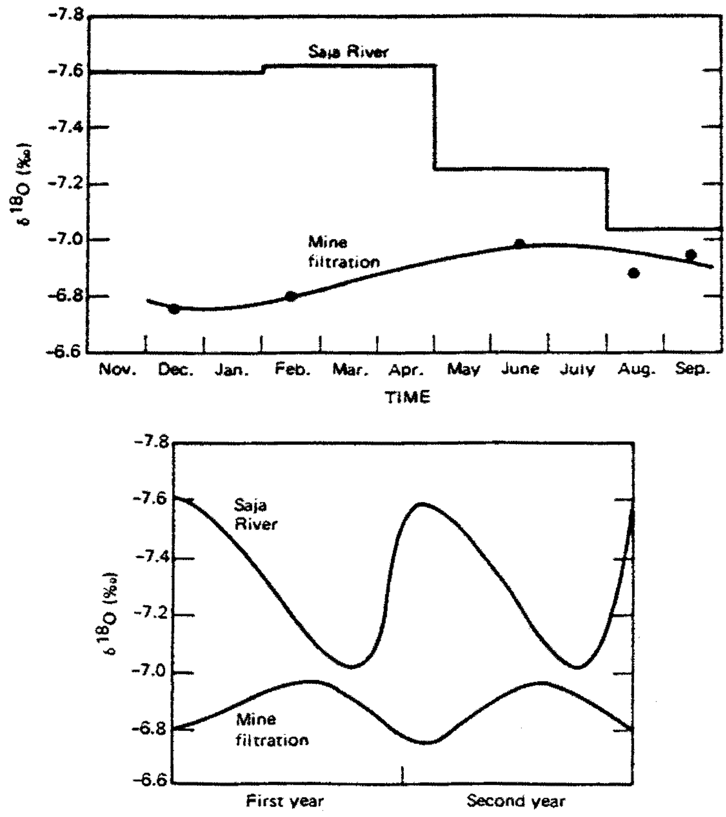

FIG. 3. Variation in $\delta^{18}O$ with time at the Saja River and mine discharge.

which were collected at different times during the period of time defined by each line. The results confirm the assumption made above, i.e. values that were more negative (higher elevation of precipitation zone) during winter. In the case of mine drainage water, a periodic variation in $\delta^{18}O$ has also been observed, but with a different pattern. Such $\delta^{18}O$ variations, on an enlarged time-scale, are shown in Fig. 3. Both the Saja River and the mine discharge water present similar periodic $\delta^{18}O$ variations, with a difference in time of about 3 months. This period of time should represent the transit time of the water between the river and the mine. As expected, the $\delta^{18}O$ variations in the mine discharge water are strongly smoothed by the groundwater reservoir.

The contribution of the Saja River to the mine drainage flow, calculated from the data presented in Table I, amounts to ~100%. Nevertheless, this contribution

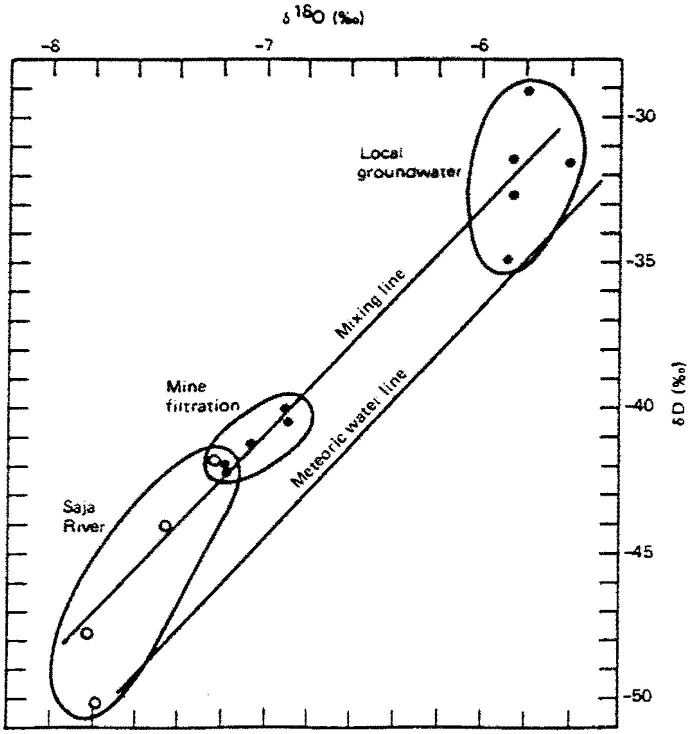

FIG. 4. δD–$\delta^{18}O$ diagram of the different groups of water samples.

cannot be considered acceptable, because in this case the sampling was carried out during the months of September to November when the $\delta^{18}O$ value in the Saja River is almost at its lowest and in the mine almost at its highest (Fig. 3). The $\delta^{18}O$ and δD values shown in Tables II and III are more representative of the average values for the whole year and give a mean contribution of about 72% from the Saja River. The difference (32%) should correspond to the contribution by local precipitation.

A diagram of δD versus $\delta^{18}O$ using the data from Table III is shown in Fig. 4. As expected, the three groups of points corresponding to local precipitation, the Saja River and mine drainage water fit satisfactorily to a mixing line, confirming the interpretation previously mentioned.

3.3. Flow rate lost at the Saja River

After having proved, by means of δD and $\delta^{18}O$ analyses, that most of the mine drainage flow was emerging from the Saja River, an investigation was planned to identify the possible loss of water within the stretch of river which flows over the outcrops of Gargasian dolomite and limestone (Fig. 2). The river discharge before and after this outcrop was measured by the dilution method (tracer injection at a constant flow rate) using ^{131}I as the tracer. The same tracer solution and the same injection system and, therefore, injection flow rate, were used for the two determinations in order to reduce the relative error. The loss in flow rate obtained at the Saja River was about 200 L/s for a total river discharge of 9.12 m^3/s.

Afterwards, the whole stretch of the river was thoroughly inspected and a zone where water of the Saja River was infiltrating into the karst system was visually observed. An injection of artificial tritium was made at this zone; the results obtained are described in the following section. According to the morphology of such an infiltration zone, a rapid increase in the infiltration rate with river discharge could be expected so that a major contribution of the river to the mine drainage flow could be possible. It should be pointed out that the average discharge of the Saja River is about 30 m^3/s and, during the rainy periods, flow rates of about 100 m^3/s are not infrequent.

3.4. Experiment with artificial tritium

Artificial tritium (3.5 Ci) was injected at the above mentioned infiltration zone of the Saja River.[1] The result of this experiment was positive. Tritium reached the mine about 20 days after injection and the breakthrough curve shown in Fig. 5 was obtained. Electrolytical enrichment of the water samples was needed to measure the low tritium concentration found in the mine drainage water. Owing to unfortunate circumstances, sampling of this water had to be stopped about 110 days after tracer injection and about 2 years elapsed before it was possible to continue. The tritium concentration in the mine discharge water had then fallen back to approximately the same value that had existed before injection of the artificial tritium.

An average transit time of 62 days was obtained from the breakthrough curve. The volume of water drained into the mine during this period of time was about 6.4×10^6 m^3. This represents the approximate volume of the groundwater reservoir existing between the river and the mine with which the injected tritium was mixed.

Integration of the breakthrough curve gives a value of 12.3 $\mu Ci \cdot m^{-3} \cdot d^{-1}$. Taking into consideration the flow rate of the mine water, a value of 1.27 Ci was obtained for the activity of the emerged tritium, which only represents 36.4% of the total injected activity. A possible explanation for this result could be that the remaining tritium activity (63.3%) had been retained in the microfissures of the karst formation (secondary porosity). Only the tritium flowing through the solution channels and the main fractures of this formation (primary porosity) would be drained during the first 120 days of the experiment. The tritium trapped in the microfissures would be

[1] 1 Ci = 3.70×10^{10} Bq.

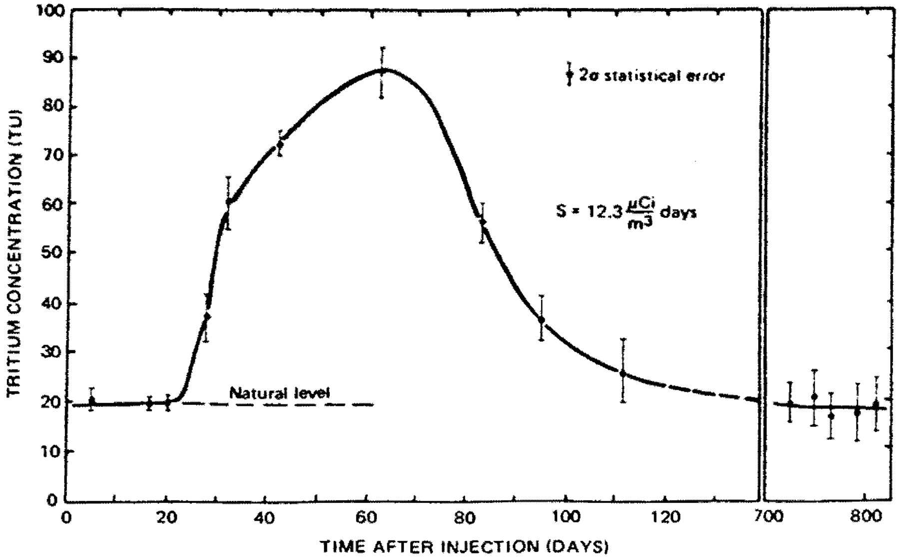

FIG. 5. Breakthrough curve of the tritium injected at the infiltration zone of the Saja River.

leached out from the rock at an extremely slow rate and for this reason cannot be detected in the emerging water. The exchange of tritium with clay formation water could also contribute to the tritium losses but, most probably, this was only a minor contributor.

On the other hand, the yearly variations in the isotopic composition of the water in the Saja River and in the mine filtration, shown in Fig. 3, can also provide information on the volume of the groundwater reservoir on the basis of the smoothing effect produced by this reservoir. A well mixing model and a sinusoidal input function is accepted for this evaluation. Let us call C_m the mean isotopic composition at the input (Saja River) and ΔC the maximum deviation of the isotopic composition with respect to C_m (maximum and minimum of the sinusoidal function). The isotopic composition at the output of the system C_t is given by the equation

$$C_t = C_m + \frac{\Delta C}{\dfrac{1}{t_r} + 4\pi^2 t_r}\left[\frac{1}{t_r}\sin 2\pi t - 2\pi \cos 2\pi t\right]$$

where t is the time and t_r is the turnover time given by the expression

$$T_r = \frac{V}{Q}$$

where V is the volume of the groundwater reservoir and Q is the flow rate referred to the unit of time (1 year).

The input and output functions of Fig. 3 correspond to a value of $t_r = 0.43/a$. The flow rate at the output is 1.2 m^3/s or 3.78×10^7 m^3/a. From these values, a value for the volume V equal to 16.3×10^6 m^3 is obtained. The relationship between the volume given by the tritium experiment (6.4×10^6 m^3) and the above value is 0.39, which is very close to the fraction of recovered tritium. This result seems to confirm the hypothesis previously given for tritium losses. The volume given by the tritium experiment might correspond only to primary porosity, while the volume obtained from stable isotope data might correspond to total porosity.

Finally, evaluation of the dispersivity of the involved karst system has been carried out on the basis of the width of the experimental breakthrough curve. A Gaussian model has been accepted for the calculation. The dispersion coefficient obtained amounts to $D \simeq 0.2$ m^2/s. The mean velocity of the groundwater flow was about 64.5 m/d or 7.47×10^{-4} m/s. Therefore, an intrinsic dispersivity for the aquifer of $D_0 = 0.2/(7.47 \times 10^{-4}) = 267.8$ metres is obtained.

4. CONCLUSIONS

Analysis of thermonuclear tritium has shown that mine drainage water is related to recent precipitations. Comparison of the δD and $\delta^{18}O$ values for the different waters involved (local groundwater, Saja River and mine drainage water) has resulted in the conclusion that the Saja River is responsible for about 72% of the mine drainage water. The hydraulic connection between the two water bodies was demonstrated by injecting artificial tritium into a sinkhole fed by the Saja River. This sinkhole is located in a stretch where the river crosses an outcrop of the same calcareous formation bearing the mineral veins.

The results obtained contradict the predictions made during some previous studies which were based on theoretical evaluation of the water infiltration through the existing dolines. This demonstrates that only direct techniques can lead to a solution for problems of this kind. It should be mentioned that a second injection of artificial tritium made by Ruiz-Mateo [4] into the sinkhole of the large doline mentioned in Section 2 also confirmed our results. The injected tritium did not travel to the mine and was detected in a spring located in the opposite direction. This happened in spite of the fact that the doline was situated at the same anticlinal of the mine.

REFERENCES

[1] TRILLA-ARRUFAT, J., et al., Sobre el Origen y Dinámica de las Aguas Fluyentes a las Explotaciones Mineras de Reocín (Santander, España), SIASMOS, Granada (1978).

[2] LOPEZ-VERA, C.F., et al., Estudio Hidrogeológico Preliminar de la Mina de Reocín (Santander, España), SIASMOS, Granada (1978).

[3] FERNANDEZ-RUBIO, R., Asturiana de Zinc SA, Torrelavega, España (1984) (Internal report).

[4] RUIZ-MATEO, A., Personal communication, 1985.