# INVESTIGATIONS ABOUT THE ORIGIN OF WATER INFLOW AT REOCIN MINE (SANTANDER, SPAIN)

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## ABSTRACT

With the aim of determining the sources and amount of the different water irruptions in the underground mine of Reocín (Zn and Pb), under karst conditions, the chemical characteristics of these waters are studied, in space and in time, together with the temperature evolution. The microorganisms present in the water are also employed as natural tracers, together with the isotopic contents. The main entry comes from the river water; the next one is deep water related with a diapir; a small amount is provided by infiltration water through the old mine works.

## INVESTIGACIONES RELATIVAS AL ORIGEN DEL AGUA FLUENTE A LA MINA DE REOCIN (SANTANDER, ESPAÑA)

## RESUMEN

Con la finalidad de determinar la procedencia y los caudales de agua afluentes a la mina subterránea de Reocín (Pb y Zn), ubicada en un sistema hidrogeológico kárstico, se estudia el quimismo de las aguas, en el espacio y en le tiempo, junto con la evolución de la temperatura de las aguas. Se emplean, también, como trazadores naturales, los microorganismos presentes en el agua, junto a isótopos ambientales naturales. La principal entrada procede de agua de ríos, le sigue el agua profunda relacionada con diapiros, y la cantidad menor de agua es la infiltrada a través de antiguos trabajos mineros.

## INVESTIGATIONS SUR L'ORIGINE D'EAU DANS LA MINE DE REOCIN (SANTANDER, ESPAGNE)

## RESUME

Dans le but de determiner les différentes origines et les débits relatifs d'eau arrivant dans la mine souterraine de Reocín (Zn et Pb), située dans un système hydrogéologique karstique, on étudie le chimisme des eaux, dans l'espace et dans le temps, ainsi que l'évo-

lution de la température des eaux. On emploie, aussi, comme traceurs naturels, les microorganismes existant dans les eaux , ainsi que les isothopes naturels. L'entrée principale a son origine dans les rivières; une autre partie l'a dans l'eau profonde en rapport avec des diapirs, et finalement, une petite quantité d'eau provenant de l'infiltration à travers des anciens travaux miniers.

## AUSZUG

Um die Herkunft des Wasserzuflusses in das Untertage-Berg werk in Reocín (Zn und Pb), das sich in einem hydrogeologischen Karst-System befindet, ermitteln zu können, wird die chemische Zusammenstzung in Zeit und Raum zusammen mit der Temperaturentwicklung des Wassers untersucht. Dazu wird ausserdem die Untersuchung der im Wasser vorkommenden Mikroorganismen sowie des isotopischen Gehaltes zu Hilfe genommen. Der Hauptzufluss entstammt Flusswasser, dann folgt das Tiefen-Grundwasser, das mit diapir zusammenhängt, und ausserdem sickert eine geringe Menge aus den alten Bergwerksarbeiten ein.

## INTRODUCTION

The underground mine at Reocín is situated in the North of Spain, 8 km. from the Cantabrian coast (fig. 1).

The mine has been worked since the times of Roman domination (surface and underground calamine mining), though only in the middle of the last century, with the Royal Asturian Mining Company (RCASA), did it reach such a volume of production that it became the most important supplier of zinc to Europe (1).The present production of the mine is about 600,000 tons of mineral per year, and the amount accumulated runs to some 20 million tons (2).

LOCATION MAP

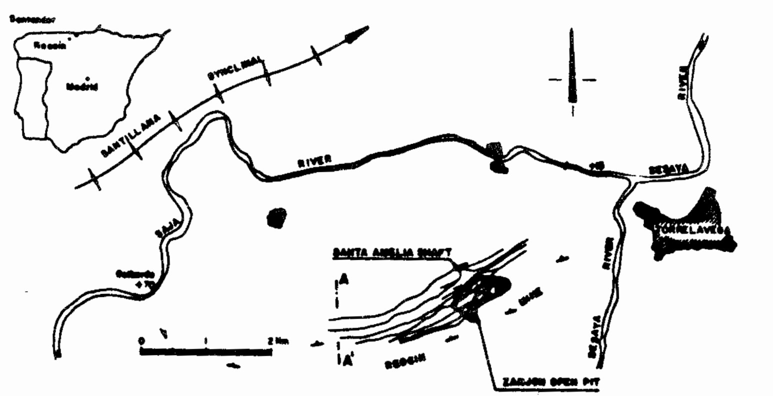


*Figure 1*

The mineral deposit, massive or in impregnations and fissure-fillings (1), appears in banks of between 0.5 and 5m. thick, in the lower third of the dolomite coral reef of Middle Aptian (fig. 2) (there may be up to 3 approximately parallel bands). On the surface the mineral is calamine, then it changes, as it goes deeper, to blende or sphalerite, togheter with complex sulphurs: wurtzite, shale-blende, galena, marcasite, melnicovite, pyrite, etc.

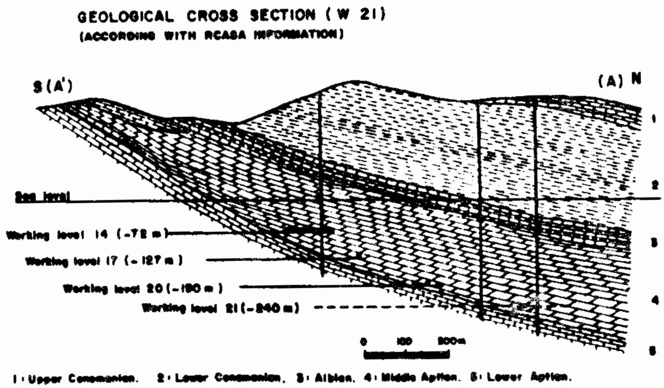


*Figure 2*

The underground workings reach down to 240m. below sea-level, and to drain the mine it is necessary to pump out about 1,100 l/sec., which involves an annual energy consumption of about 35 million k.w.h., thus accounting for approximately a quarter of the technical costs of mining operation (2).

## HYDROGEOLOGICAL SITUATION

On the evidence of the information provided by the Mining Geology Department of RCASA, we can state, in synthesis, that the coral reef limestone of Middle Aptian change laterally, through secondary dolomitisation, into dolomite, in general massive and compact, where the mineral deposits are found (fig. 3). The carbonated bank, with a thickness of about 140m. in the mine area, constituted an acuifer with porosity due to dolomitisation and is furthermore greatly karstified.

In the roof we find Lower Albian, made up of marls and marly limestones more or less sandy (aquitard), while in the wall just next to the ore body there is Lower Aptian, made up of marly limestones and slaty marls (aquifugue).

Other aquiferous formations are to be found in the roof and in the wall but the whole behaves as a multi-layered aquifer, such that the "sump" effect, produced by drainage of the mine, is only transmitted in the karsty aquifer of the Middle Aptian.

The mine is situated on the southern limb of the Santillana synclinal, with a large curvature radius (fig. 1 and 4), and a SW-NE axis, which dips towards the NE, with a slope of 10º to 20º. In the area of the mine the dips are between 25º to 35º towards the NW (fig. 2), and the dominant fracturing is N 5º W/80º W, approximately orthogonal to the stratification (fig. 5).

Some faults, both direct and rotational, produced by diapiric thrusts, are of great significance for hydrogeological behaviour, since along them there is a rise of saline water towards the mine.

The aquiferous circulation in the Middle Aptian takes place through dissolution cavities, normally of a hieght of between a centimeter and a metre, developed longitudinally for an observable distance of several metres, and clearly adapted to the stratification. These cavities are usualy covered by dolomite and calcite crystallisations, with pyrite and marcasite, all of a subaquatic deposit, and could include fillings of sands from Lower Albian.

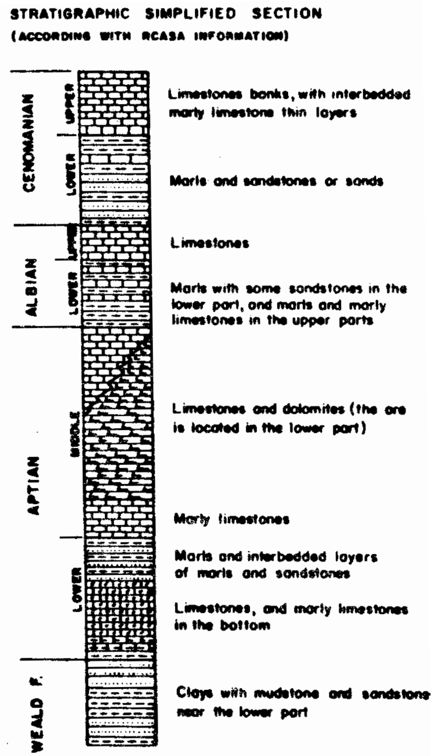


*Figure 3*

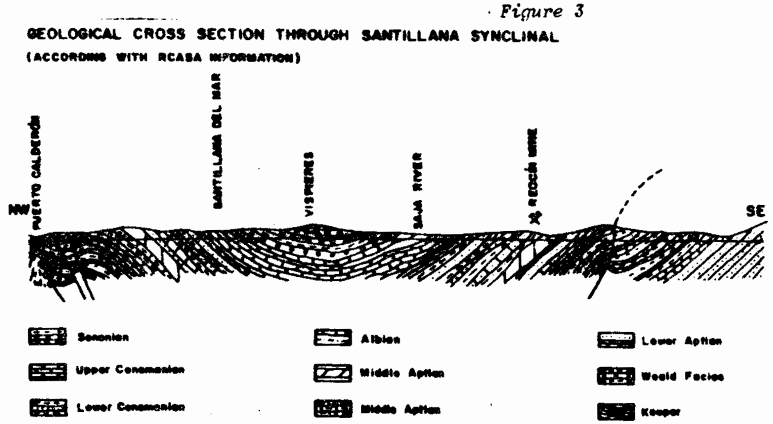




*Figure 4*

In the aquifugue of the wall (marly limestones), mine drainage produces water circulation, under pressure, through the subvertical fractures of a milimetric width. When these fractures (N 5ºW) continue in the limestone-dolomite Middle Aptian, they increase in size, by dissolution, to centimetric and decimetric measurements, and are usually highly developed vertically. All this is clearly to be seen in the West Section of the underground mine.

FRACTURES DIAGRAMM (over 156 measures distributed in undergroud working levels)
(FERNANDEZ-RUBIO, 1980)

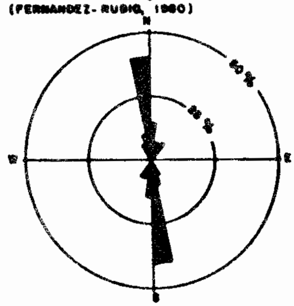


*Figure 5*

The existence of a great number of dolines in the vertical of the mine; the old underground workings, which reach the surface; and the new Zanjón open-pit mine, in the upper part of the ore body: all this means that the rainfall (an average above 1,300 mm./year) provokes sudden entries of water into the underground mine. At peak points, the inflow of water can be considerable, carryng a great deal of solid matterial, even though this does not represent an important proportion of the total volume of water pumped out.

Another hydrogeological aspect which should be pointed out is that the river Saja, with an extensive hydrographic basin and with a flow that can reach several hundred cubic metres per second, crosses the carbonated formations of the Middle Aptian in two points (fig. 1). And indeed the karstification below sea-level, which can be seen in the mine and has been demonstrated in several exploratory-holes, seems to be a consequence of a underground paleocirculation. If this was the case, then the river waters on their entry into the syncline, crossing the carbonated formations over more than 350m. in a fairly broad river channel (height +70), would percolated, to drain off after where the river crosses again the same Middle Aptian, and to leave the syncline (height +15), with a underground hydraulic gradient of approximately 0.8%.

In this upstream sector (fig. 6) I have shown (3) that there exists, under present conditions, a local flow of water towards the river (gaining stream) in all the aquiferous formations, except in the limestone of the Middle Aptian, where the effect of the mine drainage, as has been demonstrated by the piezometers, produces a loss of river water to the aquifer (losing stream).

From the chemical point of view, which we will discuss in some detail later, we must point out that the waters of the river Saja, with less than 300 mg./l of dissolved solids, show a predominance of bicarbonates and calcium or magnesium, with a relatively variable composition, depending on the proportions of the mixture of strictly surface waters and underground waters.

RIVER - AQUIFER RELATION AT GOLBARDO AREA

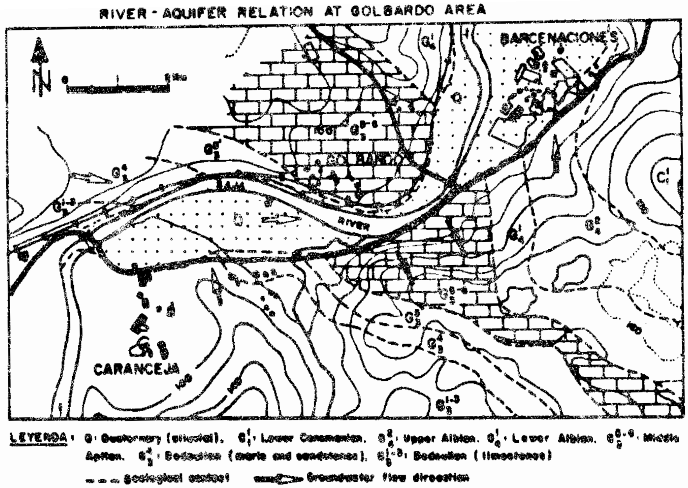


*Figure 6*

## MINE DRAINAGE

Under natural conditions, and despite the fact that we have no exact data (the drainage was begun more than a hundred years ago), it seems logical to think that water must have been present in the mine, at least from a height of +50 (the Santa Amelia Shaft is opened at +107 and reaches a depth of -228m).

From 1959 on, basing our calculations on the amount of energy consumed by the mine drainage pumps, and bearing in mind its characteristic features, it is possible to make an overall estimate of the flow pumped out (fig. 7). This estimate enables us to establish the generally increasing tendency shown by the pump-flow and to give an average increase which is of the order of 35 l./sec./year. This graph, which includes the monthly rainfall figures, also shows the increase in pump-flow during periods of heavy rainfall; this is due to the direct infiltrations, which I have discussed above.

It should be emphasized that, with the progressive deepening of the mine and with the lateral expansion of the galleries, the upper mined levels gradually dries out, as the water flow collects in the lower levels and in the E and W limits of the low galleries. The "sump" efect produced by the mine drainage ensures that the upper galleries and the central sector remain in the non-saturated area.

## PIEZOMETRY IN THE MINE SURROUNDINGS

Despite the fact that many investigation bore-holes have been drilled in the Santillana synclinal, piezometric controls carried out during the perforation or once this was completed are found only in seven cases. These holes, drilled between 1977 and 1979 are placed in a line, approximately 100m. NW of the deepest workings level (fig. 8). The analysis of the data obtained allows us to deduce the following:

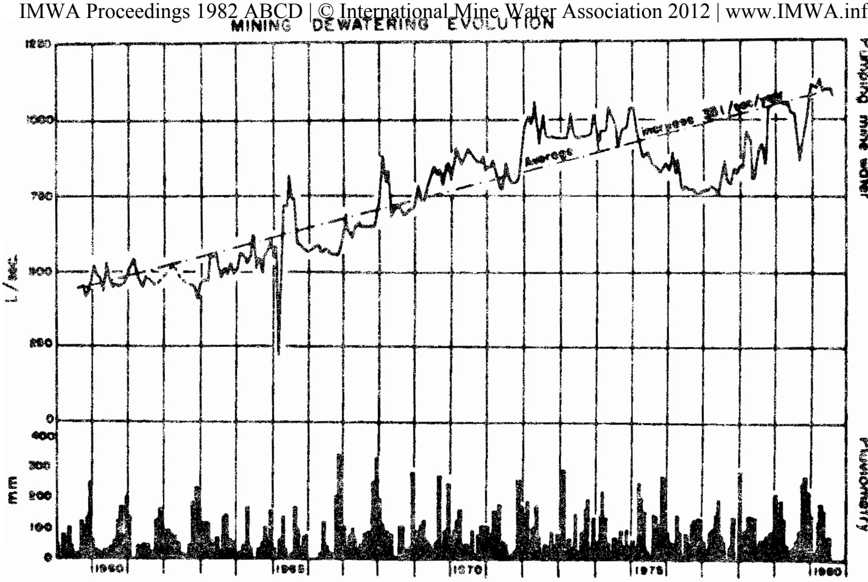


*Figure 7*

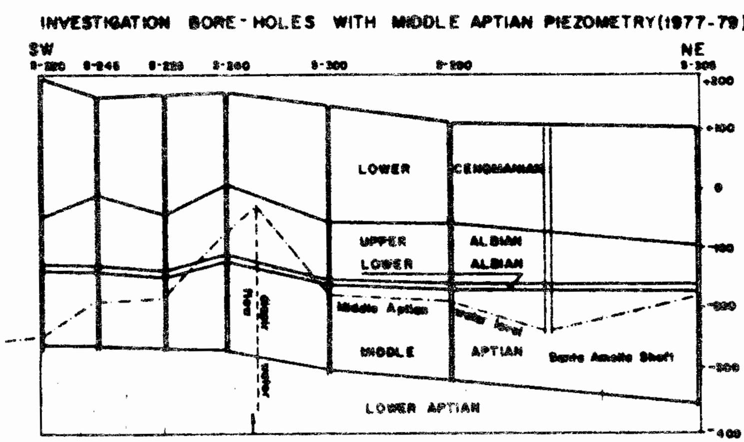


*Figure 8*

The Lower Cenomanian, made up of alternating layers of sandstones, sands and marls, with an average thickness of 180m., maintains the piezometric level at a depth of between 10 and 50m., determined by surface lateral drainage. Its vertical permeability is very reduced, although locally the horizontal permeability may be greater, due to sandy layers. As far as the mine is concerned, it forms an impermeable roof.

In Upper Albian, made up of sandstones, sandy marls, sands, limestones and dolomites, with an average thickness at investigation boreholes crossings of 100m, the piezometric level drops to depths of 130 to 230m., according to the more or less marly or carbonated nature of the rock and to fracturation and breccifying. At any rate, the effect of deep mine drainage can be observed, although the water may locally be hung, due to the fact that it is a low permeability aquifer.

In Lower Albian, of clays, marls and sandstones, with an thickness of only 10m., there are very few piezometric data. This is a formation of low permeability, but of insufficient thickness to enable it to be isolated, given the presence of fractures and the effect of leakage.

The Middle Aptian, dolomitic, with a thickness of 140m. in the lower third of which the ore deposit is located, shows a high degree of permeability due to dolomitisation, fissuring and karstification, with complete loss of water circulation during the drilling. The piezometric level falls to depths between 260 and 410m., owing to the drainage produced by the mining works on Level 21 (depth -240m.) and by Santa Amelia Shaft (depth -228m.) (fig. 9 ).

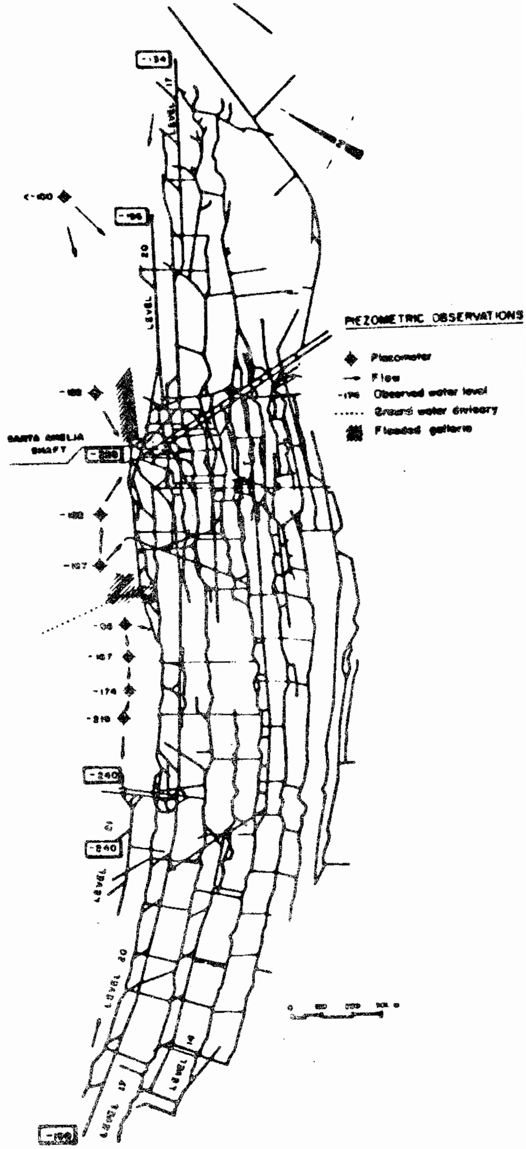


Figure 9

The few metres of Lower Aptian which have been perforated (marly limestones), give us no information as to its behaviour, but the mine workings demonstrate its low permeability as a consequence of the marl component. This may be considered the impermeable wall of the mine.

## WATER FLOW TO THE MINE

Returning to the figure 7, which illustrated the pump flow statistics, obtained on the basis of energy consumption, we should point out that these statistics are only an approximation: we must take into account the variation in energy efficiency due to pump wear, replacement of worn pumps with new ones, energy loss in valves and piping, etc. Nonetheless we should emphasize the degree to which the pluviometric variations and the flow variations correspond; this allows us to estimate the effect of rapid direct infiltration of rain water, through the natural cavities of the karst and especially in the old mine workings, and in the new open-pit workings. This rapid infiltration could be calculated, in monthly terms, in quantities of between 50 and 250 l./s., although the peak points may be considerably higher, and the lowest points much lower.

From 1979 a gauging control by means of micromolinet has been established. And, taking this control and our measurements into account, we can state that the most important inflow of water occurs al Level 21 (Western Section of the mine), from where 900 l./s. (79% of the total drainage) is pumped out. 135 l./s. reach Level 20 (also in the Western Section) (12%), and 40 l./s. comes from the Eastern Section (3%). This produces a total pump-flow

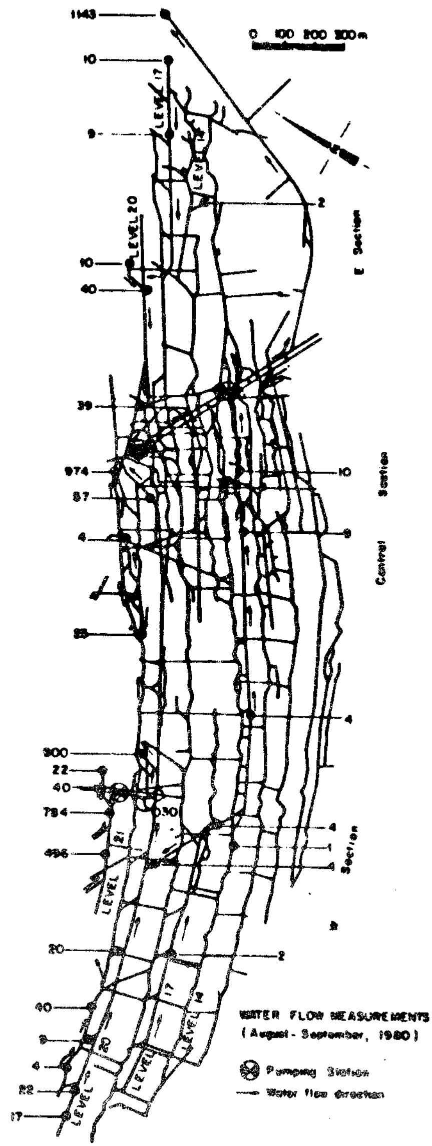


*Figure 10*

from Level 20 to Level 14 of 1,075 l./s. (95%). At Level 14 another 10 l./s.(1%) flow in and we would have to add about another 60 l./s. not accounted for (5%), which would give us a total of 1,140 l./s. pumped to the outside. Figure 10 shows the gauging yield in August-September 1980.

One important conclusion to be drawn is that the Western Section of the mine account for 91% of the water registered; the Eastern Section account for 4%, and the remainder is made up of unidentified entries. These percentages may vary during the year, according to the pluviometry, but they show that the drainage problem is firmly centred in the Western Section.

## WATER TEMPERATURE

The temperature of the water can be used as a "tracer" to determine the path followed by the water. The temperature of underground water in slow flow approximates, by adaptation, to that of the subsoil, but this equivalence can be changed by the rapid circulation of large volumes, which modify the geothermic distribution.

With an average temperature in the surface environment of 14.1°C (at a height of +15), and for a decreased of 3 ºC per 100m. depth, the theoretical temperatures obtained at the different levels of the mine are as follows:

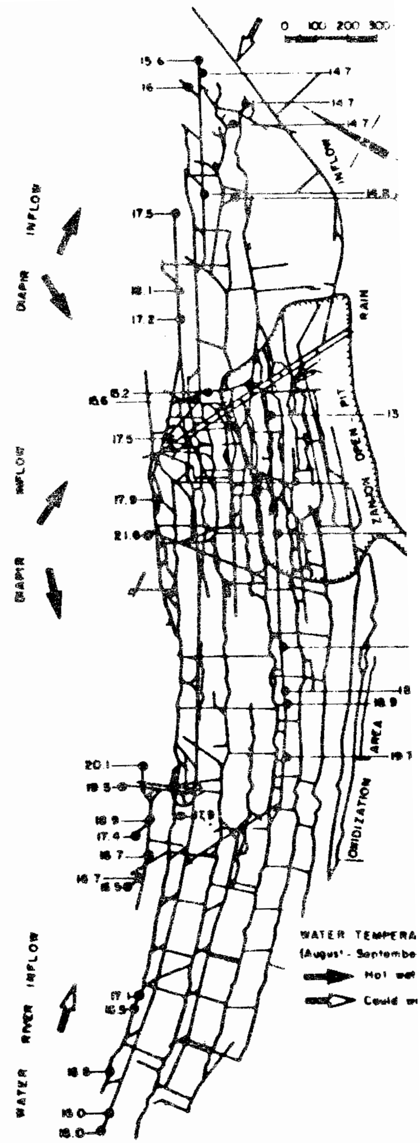


*Figure 11*

| Level | Depth (m) | Temperature (ºC) |
|---|---|---|
| 14 | - 72 to - 85 | 16.7 to 17.1 |
| 17 | -127 to -140 | 18.4 to 18.7 |
| 20 | -190 to -200 | 20.2 to 20.5 |
| 21 | -240 | 21.7 |

The ventilation in the mine and the exothermic reaction due to oxidization may modify the temperatures, although these factors only affect the air, the surface of mining works or very limited water flows.

The thermic peculiarities shown by the water temperatures may provide information of great interest. In figure 10 we show the temperatures of the water in August-September 1980.

In the Eastern Section of Level 14 we can see that the temperatures in the East are low, as a consecuence of direct and rapid rain-water infiltration, since this area is situated underneath open mining works (which do down to a level of 0 m.). In the West, on the other hand, where the rock covering is thicker, the yield is less than 0.5 l./s., and the waters are very mineralized, by sulphur oxidization (exothermic reaction); here the temperatures increases noticeably.

At Levels 14 an 17 of the Eastern Section, cold water flows in a very karstified area and one with frequent subvertical and very open fractures. This flow even carries with it a considerable quantity of surface sand, within an interval of minutes after intense rainfall.

Again in the Eastern Section, Level 20 shows itself to be a sector where the temperature of water coming in through fractures or bore-holes is higher. This anomally seems to be caused by an inflow of deep water through faults, even though the yield is very slight (less than 5 l./s.).

As far as the Western Section is concerned, we find, at Levels 20 and 21, an inflow of cold water from the west, the temperature of which rises gradually towards the east, as a result of a longer contact with the aquifer and owing to its mixture with warmer waters connected with a deep diapir.

If we take into account the fact that water with a temperature of 16 and 17°C, which usually corresponds to depths of -50 and -80m., according to the geothermic gradient, arises here in the west at Level 21, at depths of between -190 and -240m., we must assume that there is a rapid aquiferous descending circulation thorough karstic conduits, and that this water cannot originate from reserves in the aquifer (except to a limited extent)

As a conclusion to these remarks on water temperature, we should point out that, as is the case in the Eastern Section, the evidence of a thermic flow, connected with a deep diapir is clearly marked in the Western Section. This effect we have already seen in the piezometry (fig. 8), and will be confirmed in a chemical study.

## CHEMICAL STUDY OF THE MINE WATER

I will base my study on a sampling which was carried out in 1980, spaced out over 140 days, in the main water entries into the mine (two cross-cuts at Level 21), and in a sampling spacially spread out over the other mine water inflows, and one other analysis of the total pump-flow of the mine, with a total of 53 analyses.

As far as both series of samples from this cross-cuts (Level 21) are concerned, we can detect that the variations of $Ca^{++}$ and $Mg^{++}$ are produced inversely; the $Na^{+}$ is subject to gradual changes, with a tendency to increase; and the $K^{+}$ and $Cl^{-}$ remain very constant.

If we compare the water in both cross-cuts, we observe that the near one to the diapir inflow, contains a greater amount of $Cl^{-}$ and $Na^{+}$ and less $Mg^{++}$. The amounts of $SO_4^{=}$ and $Ca^{++}$ undergo similar fluctuations and $CO_3H^{-}$ and $K^{+}$ behave practically indentically in both cross-cuts.

These waters show a great chemical similarity to those of the river Saja at Golbardo (+70m.), with a greater amount of $CO_3H^{-}$ in the underground waters, which is logical given that we are dealing with a carbonated aquifer (fig. 12). When we carry out comparisons, with samples spread over a certain period of time, we notice parallel fluctuations in the river waters and in those of the principal entries (cross-cuts at Level 21) insofar as the contents of $SO_4^{=}$, $Mg^{++}$ and $Na^{+}$ are concerned; while as far $CO_3H^{-}$ and $Ca^{++}$ the composition of the mine water shows few changes.

With respect to the spacial sampling of waters which flow into the mine, there are many observations which can be made (fig. 13 and 14). Among these, considerations of the chemical facies are particularly significant, and here we can differentiate the following groupings:

Chlorided Water

Sodium chloride waters form a clear grouping, with a great amount of dissolved solids, connected with the diapir character of the Central Section of the mine.

Since we are, for the most part, dealing with hidden exits, situated in flooded

CHEMICAL COMPARISON BETWEEN THE SAJA RIVER WATER AND THE MAIN UNDERGROUND WATER INFLOW (August 1980)

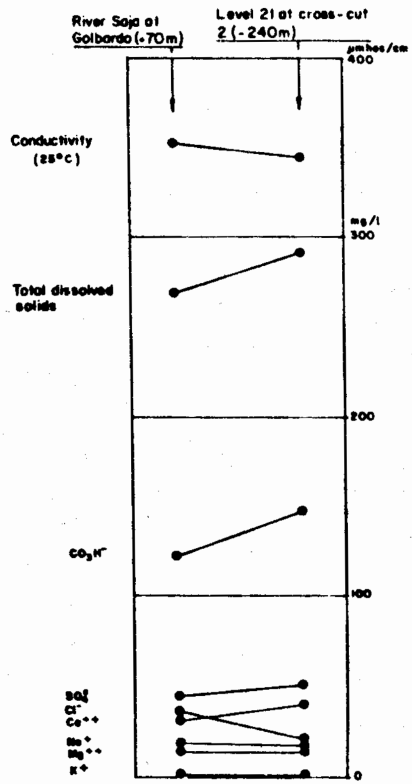


*Figure 12*

workings at Level 22, or in inflows taking place beneath the galleries carrying the water, it is difficult to determine the exact yield, though we can estimate this as being between 50 to 100 l./s.

## Sulphated water

Here we can clearly distinguish sodium sulphated waters which arise under great pressure through an investigation hole (drilled till 700 m depth, at Level 20, Western Section), with a strong sulphohydrate smell. The average volume is 6 l./s., but there may be other derivations through fractures towards Level 21.

The most general facies within this water-group is that of magnesium sulphated water, which is found in falling infiltrating water through old mine workings, in conditions which produce an oxidization of the metallic sulphurs.

Many of these waters carry nitrates, which could come from the decomposition of the old wood timbering. The yield measured was of the order of some tense of litres per second, which could be increased by inflow through some hidden entrances.

For a approximation to this facies we will have to refer to mixed sulphates waters, mixed with calcium bicarbonated water, with a greater percentage of magnesium or calcium, depending on the mixture. All of this waters show nitrates. The yield may reach some tens of litres per second.

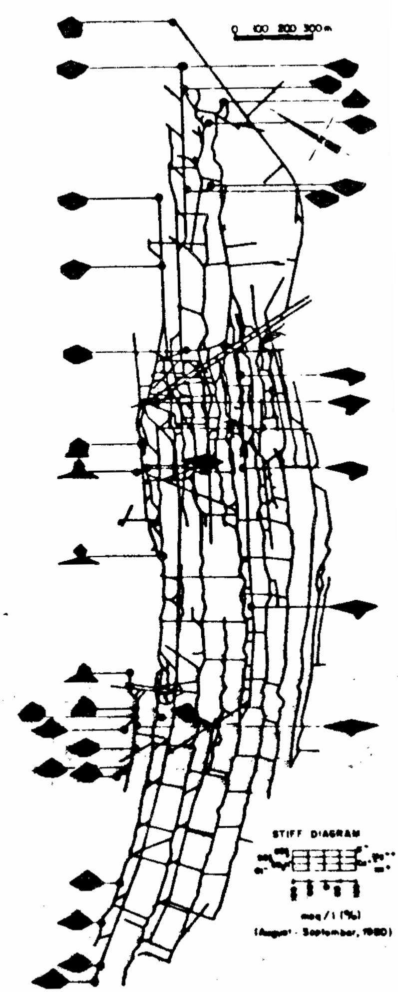


*Figura 13*

### Bicarbonated Water

Given the ambit of limestone and dolomitic rocks where the mine is located, these waters are the most abundant. They can be primarily calcium, magnesium or mixed waters, according to the rock lithology. They occasionally contain nitrites. They arise principally in the Western Section of the Mine and their yield can exceed 800 l./sec., without counting the contribution made by other mixtures.

### Mixed Water

This group is made up of waters of an intermediate character, between the facies mentioned above.

There are thus mixed magnesium waters, which arise for the most part in dolomites of the roof of the Eastern Section. Their yield is of the order of 10 l./s.

There are also mixed calcium waters, coming from the marly limestones of the Lower Aptian, with a high content of sulphates and a very low yield.

Finally, we have mixed waters in the anionic and cationic sense, which are a mixture of the other types mentioned. Among these we should mention those produced by the total drainage of the mine.

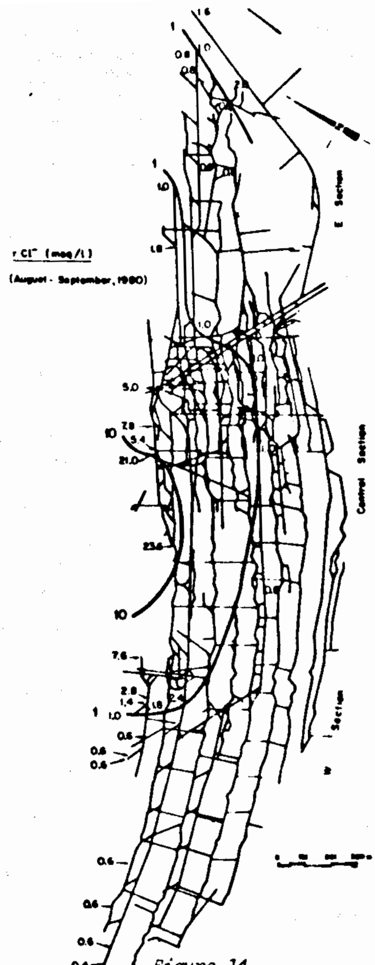

*Figure 14*

## SOLID MATTER TRANSPORTED BY THE WATER

The main water entries into the mine carry an important amount of sediments in suspension; in the Eastern Section this matter is clearly made up of superficial sand and slime. However, it was not so easy to determine the origin of this material, in the main entries at Level 21 (Cross-cut no. 1 and 2). In order to attempt a clarification of this, I took samples of the solids deposited in this Cross-cut no. 2 and of the muddy sands of the terrace of the river Saja, in the Middle Aptian outcrop in Golbardo (fig. 6). Both samples were studied (4), and the following data was obtained:

The sediment carried by this main ground water entry at the mine, with a greater percentage of lutitic fraction, shows smaller particle size than is found in the sediment of the river Saja (fig.15), but the degree of granulometric selection is very similar.

As far as the mineralogical composition of the sand fraction, both samples show the same frequency distribution on heavy minerals (density greater than 2.9), except in marcasite, find only in the solids transported by ground water inflow at the mine. The diamagnetic fractions (density less than 2.9) are the same in both samples. The only difference are to be found in the paramagnetic fraction which represent, in both cases, a very small percentage of the total (less than 8%).

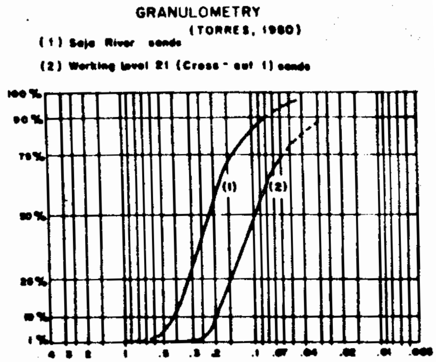

*Figure 15*

According to this data, there seems to be a close connection between both samples, and it is probable that the mine sand sample, transported by the water, by means of the circulation through karsty cavities, has its origins in the river Saja sediments.

## FAUNA TRANSPORTED BY THE WATER

With the aim of compiling more information about the origin of the different waters which flow into the mine, I planned a study of the fauna of these waters, with the inestimable help of M. ROUCH and Mlle. GOURBAULT of the Underground Laboratory of Moulis (France) (5).

The research project consisted in a systematic filtering of the water entries at significant points in the mine (fig.16 ). The principles on which it is based this technique are the followings (5):

In the surface runoff of water we frecuently find a downstream displacement, sometimes a passive one, of numerous species of invertebrate animals. This is what is know as drift. We can distinguish between: a) a constant drift, which is produced by chance, continuously, and is in general not very abundant; b) a behaviour drift, characterised by the displacement of species at certain hours of the day; and c) a catastrophic drift, which takes place as a result of river flood, snow melting, etc.

Underground waters in a karst area allow a drift, has been studied mainly in cases of river flood. Certain groups of fauna can be carried, in considerable amounts, such as is the case with the Crustaceans, especially the Copepods, microscopics forms of between 0.3 and 1.2 mm., of which the two principal types are the Cyclopids and Harpacticids.

The filtering of these waters allows us to determine the fauna population, and here we can distinguish hipogene forms (strictly subterranean) from those of epigene origin (which normaly lie on the earth's surface, but which do down to an underground area by means of river losses or the infiltration of rain water).

Some of these epigene species can develop underground and form considrable populations. These are called troglophiles, as contrasted with troglobes (subterranean hipogenes), and with trogloxenes (epigenes which do not develop in underground surroundings).

Since these animals belong to different ecological categories, they can be used as tracers of the aquifer medium.

In our study of the Reocín Mine we used silk filters with a net of 110 micrometres, to capture this microscopic fauna.

The filters were placed at seven points where the water enters Levels 17, 20 and 21 (fig. ), and were left in place for four days changed daily. This meant a total of 430 hours filtering, though in some cases the silk filters was broken by the considerable amount of solid matter transported and the great amount of water which passed through. In all, several million litres of water was filtered.

In the filters at points 1 and 2 we collected, as well as an important amount of white sand (with a lot of quartz and mica), a considerable quantity of vegetable matter (wood remains, leaves, fern spores, conifer pollen, moss and micelid filaments). Many of these remains have no connection with the matter which man has introduced into the mine, and are on the other hand very similar to that obtained from the pumping which was carried out at a well-point of the alluvial terrace of the river Saja at Golbardo.

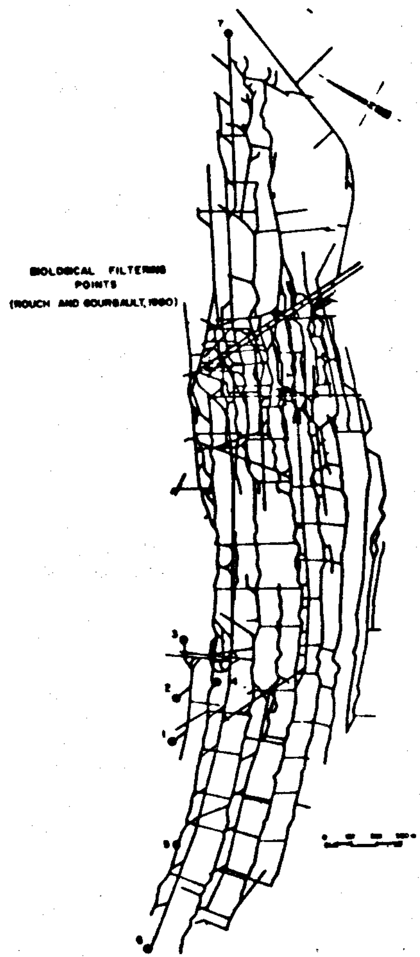


*Figure 16*

At Cross-cut no. 2 (point 2), no fauna was collected, but at Cross-cut no. 1 (point 1) we did collect some examples, and these, in spite of the fact that they were very few n number, have been of great value, since they have brought us examples of: an aquatic surface dipter (Chironomidae); a Nematod typical of damp soil; an adült Cyclopid (Paracyclops fimbriatus), a common surface type, although it can develop underground; a Harpacticid (Moraria sp.) which does not belong to any Western European species so its ecological environment cannot be determined, although most Moraria are epigene forms (there are some troglophiles, and only one species is really troglobe). Thus, despite the small amount of fauna we captured, it seems that we can state that it is of epigene origin and is probably connected with a river flow.

At Level 21 towards the East (point 3), no fauna was captured, vegetable remains were very scarce, the amount of sand was considerably reduced (there was quartz), and the most abundant matter was a reddishbrown clay similar to that which the water deposited in the drainage gallery of Level 20; so part of the water at this inflow point could have come from filtrations from that gallery.

At Level 20 we investigated the water which flows in from the artesian deep bore (point 4), but we were not able to take samples directly at the emergence point, but after the water's passage through an old mine working which joins Level 17 and Level 20. The fauna captured here was considerable in quantity (100 individuals) and a great part was typical of the soil or the surface; only one example (Speocyclops cantabricus) belongs to a trobloge species. This Example could have come from the deep artesian bore, while the rest would be matter transported through infiltrations from the surface, and to fauna imported which developed in the mine interior.

Point 5 was placed in an inflow water collection channel. The large amount of rotten wood seems to account for an imported, colonialising fauna which is not very representative.

Point 6 was a investigation-bore at the end of the wall galery, of the Eastern Section at Level 20. The water key/tap of this borehole was opened especially to permit our sample to be collected, and our results included on troglobe example (a Crustacean of the Syncaride group) and three Moraria identical to those captured at points 1, 4 and 5. At this test point, it is probable that the opening of the bore hole, which is normaly closed, produced an expulsion of troglobe fauna typical of an aquifer, together with other fauna carried from the surface (fluvial?).

Finally, we should point out that at point 7, situated in Level 17, towards the East, the waters flow in through karst subvertical conduits, which after the rains are turbulent, and carry abundant quantities of slime, sand and a lot of vegetable remains which fill the filters quickly. The numerous species which we were able to establish were parasites of plants and roots and forms typical of damp soils; they were not aquatic and were of earthly origin, which proves the rapid and direct entry of rain water at this point, and in general throughout this gallery in the Eastern Section.

To sum up, we may state that of the 495 examples collected only two are troglobes, when under normal conditions there are very great quantities of microscopic forms in underground waters-like, for instance, the Amphipods of the Niphargus family.

However, it is still difficult to find a clear explanation of the relative lack of fauna in the main water entries into the mine. Perhaps there is a "filter" at some point in the underground route in some sector with no real karst cavities.

## ISOTOPIC CONTENT OF THE WATER

It is interesting to compare and contrast what we have described so far with the data of tritium content of the water at some inflow-points in the mine (6).

According with this data, based on a sampling taken in February-March 1977 (fig. 17), there is a gradual decrease in tritium from the extreme western end of the Western Section towards the Central Section (the sector with diapir waters). In the Eastern Section there is a high content level in the wall galery, and a low content level in the working gallery.

In the samples of December 1977 (fig. 17) appreciable variations in the tritium content were observed, compared with the earlier sampling; in all the samples taken from Level 20 the level had dropped; it had increased at Level 21; there was also a drop in the Central Section; and the level remained practically constant in the Eastern Section.

In samplings taken in January and December 1977 the river Saja at Golbardo (fig. 6) gave respective readings of 44 ± 11 and 39 ± 3 T.U.
The inflow points where the samples were taken showed considerable differences in their isotopic content and this reflects a rapid dyna-

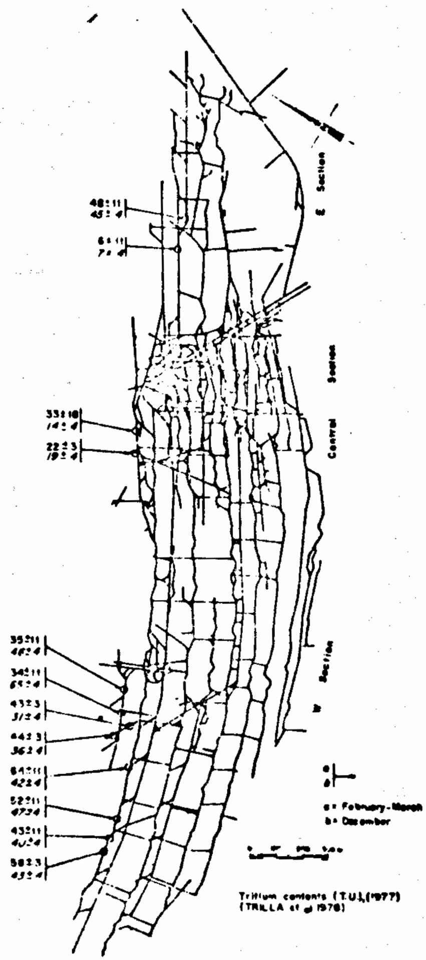


*Figure 17*

mic, affected by intense rainy periods, in which the rainfall is mixed with the waters of the aquifer in different proportions.

The interpretation of the spacial variation seems to confirm, if we take into account the investigation which has been undertaken, that in the Eastern Section we find, on the one hand, the oldest water, practically without tritium and consequently infiltrated earlier than 1952 (reserves of the aquifer and diapir water). In this Eastern Section there is also other water that has been brought in directly by the rains, without mixing with the water stored in the aquifer.

In the Central Section (with diapir water) there is a mixture of old water with other types produced by the rapid infiltration of rainfall (in a smaller proportion).

In the Western Section the most recent water is to be found at the western limit (the nearest to the river Saja at Golbardo); the water which shows signs of having remained longest in the aquifer, and which has also mixed with sodium chlorided water, is that in Level 21.

If we now considerer the variations observed in the interval of time between February-March and December 1977, and if we take into account the fact that December was a very dry month, and that the mine-deeppening works had progressed in Level 21, so that of the voluminous water inflows of Level 20 had passed to Level 21, it is easy to interpreted the general decrease in tritium content shown in all the samples (due to a drop in the amount of rain water). The increase in tritium at Level 21 would thus be due to the increase of water proceeding from the river Saja. due in turn to the greater extension of the mining works at Level 21. The time which the water stays at Level 20 is very limited (6), and it would take about thirteen days to move from Level 20 (front west) to Level 21.

The aquiferous reserves maintain a constant tritium content, but their contribution is a minority one, compared with that of the water that has infiltrated in recent years.

## CONCLUSIONS

The different methodologies employed during this investigation, to identify the origin of water inflow at the mine, are concurrent: the main entry comes from the water loss from river Saja at Golbardo (+ 70m.); the second one is connected with deep water related with a diapir, probably located at NW of the mine Central Section; the third one has its origin in the infiltrated rain water, descending directly through the abandoned mine works. Finally the smallest amount is water storing reserves in the aquifer.

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