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HYDROGEOLOGICAL INVESTIGATION AND DRAINAGE INFRASTRUCTURE AT UNDERGROUND ZINC AND LEAD TROYA MINE (GIPUZKOA, SPAIN)

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ABSTRACT

In 1977 a 491m. long ramp was developed from surface into the Troya ore body. At the bottom, when the ramp had reached the ore horizon, a sudden and important water inflow from the confined karstic aquifer at the foot wall took place.

A hydrological investigation was immediatly started with the objective of defining the characteristics of the aquifer. Two main phases of the investigation were planned and completed before a drainage system could be developed:

- Pumping test of a surface well, drilled near the vertical of the ramp's bottom.
- Pumping control of the ramp drainage system and piezometry of the well.

In addition, complementary monitoring of flow, pressure, temperature and chemistry at several points in the aquifer system as well as rainfall was established.

Upon defining the main characteristics of the aquifer system where the Troya ore body is hosted, it was planned to drill wells for pumping and piezometric control. These holes also provided complementary geological and hydrogeological information.

The pumping test performed provided information of high practical value.

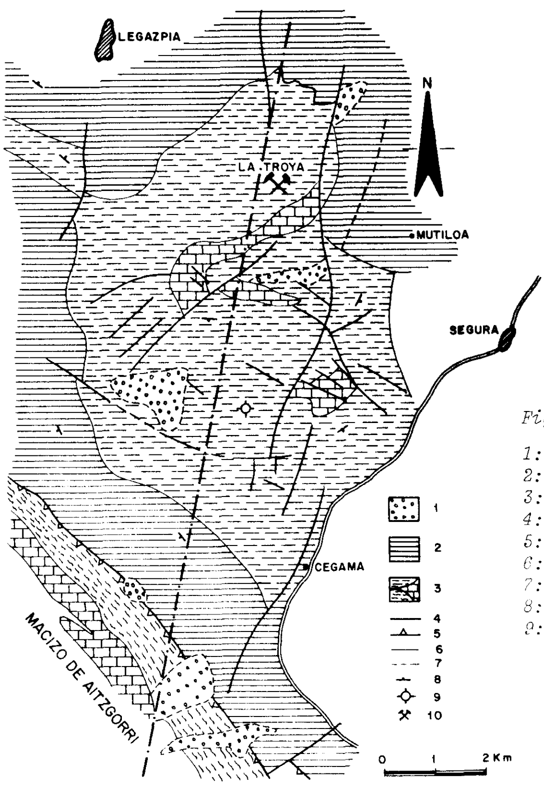


Figure 1. Geological Map.

1: Colluvial materials
2: Supra-Urgonian
3: Urgonian
4: Fault
5: Thrust front
6: Unconformity
7: Dip
8: Oil well
9: La Troya Mine

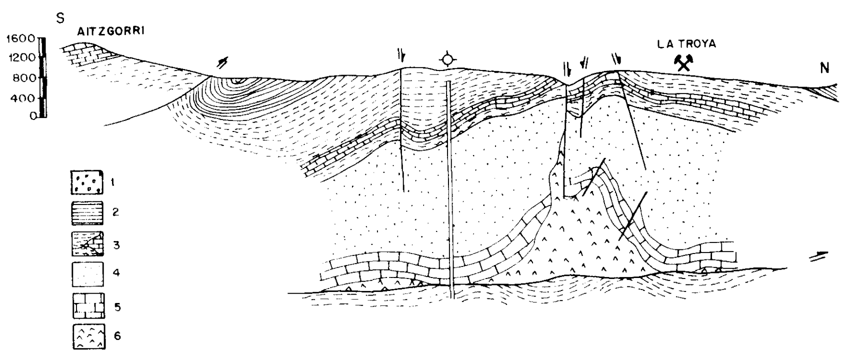


Figure 2. Geological cross section. 1: Colluvial materials. 2: Supra-Urgonian. 3: Urgonian. 4: Neocomian. 5: Jurassic. 6: Germanic Triassic.

STRATIGRAPHY

The local stratigraphy (figs. 1 and 2) begin with the Triassic (marl-gypsum germanic series) of diapiric behaviour which tends to extrude through fractures and faults. The overlaying strata are the Jurassic (limestones and marly limestones), and the Neocomian (limestones, schisty marls, sandy marls and schists). None of these strata outcrop near the orebody.

Next in sequence, the Urgonian strata are characterized by four different formations, which, from younger to older, are:

- Sandy schists with carbonaceous levels.
- Reefal limestones with frequent dolomitic levels, where the ore body is located.
- Alternating marly limestones, clays and sandstones.
- Marls.

Finally the Supra-Urgonian is characterized by clays overlain by sandstones.

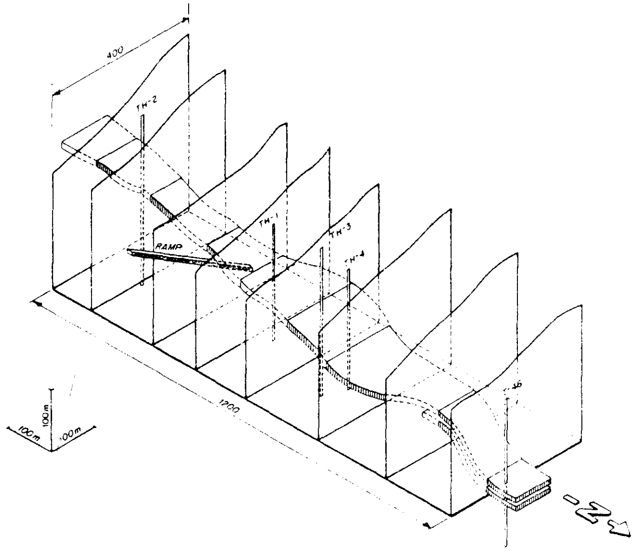


Figure 3. Isometric diagram of Troya ore body showing pumping and piezometric wells.

HYDROLOGY

The ore body has a tabular shape (fig. 3) and is located at or near the upper contact of the Urgonian reefal limestones, which, in this area, have a thickness over 200 m. and present a high degree of karstification.

The reefal limestones outcrops at the South end of the ore body (fig. 1), where the aquifer is recharged by rainfall and direct inflow from water streams.

In the future mining area, the aquifer is confined by the impermeable materials at foot-wall and hanging-wall. These materials are Urgonian marls, marly sandstones and schists.

The aquifer is confined to the East by a N-S fault system acting as a "negative barrier". To the North and West the aquifer formation gets deeper under younger formations and to the South it is limited by another fault (figs. 1 and 2).

The hydraulic resources of the aquifer have been evaluated in 40 l/sec. based on rainfall, outcroping area and karst characteristics. These resources may increase in the future as a result of induced recharge due to the drainage of the ore body.

Assuming an effective porosity of 2,5 %, the total water reserves may be estimated in 15 Hm^3.

PHASE 1 - INITIAL PUMPING TESTS

1. Execution and Controls

TH-1 well was drilled 20 metres off the vertical of the ramp's bottom (fig. 4). Initially stepwise pumping test were used to determine the optimum flow. After cleaning the well, two test were performed. The first at 27 l/sec. for 54.5 hours and the second at 38 l/sec. for 4.5 hours. Both tests were followed by recovery control test for 24 hours and 4 hours respectively.

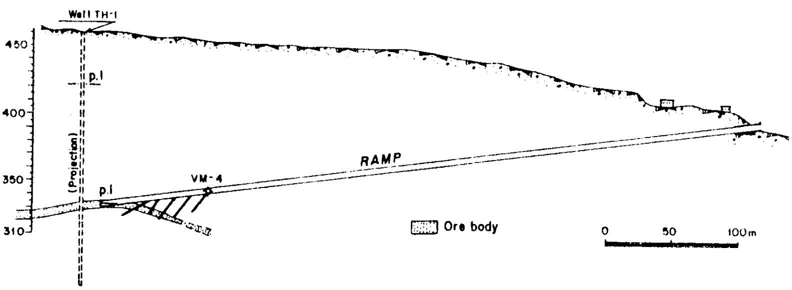


Figure 4. Access ramp showing artesian holes and TH-1 well.

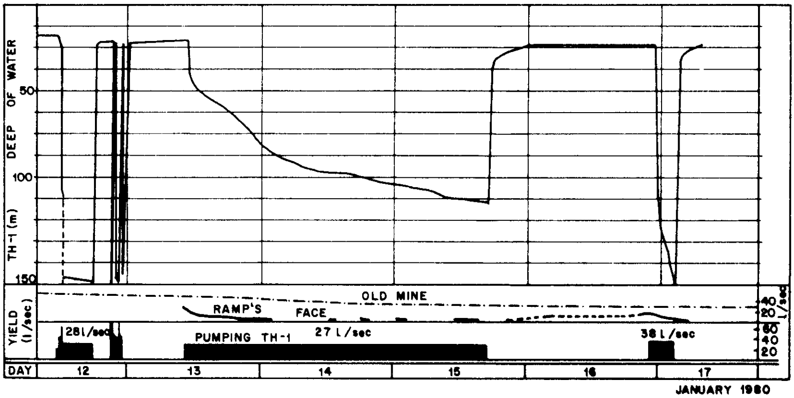


Figure 5. Hydrogram of TH-1 pumping tests showing the evolution of water flow at the ramp's face and Old Mine.

During the test, the following parametres were examined (fig. 5):

. Flow, piezometry, temperature and chemistry of the TH-1 water.

. Water inflow to the ramp, including observations of the water level, flow pumped, ramp's running water (every 10 min.) and chemistry.

. Water pressure at hole VM-4 every 30 minutes. VM-4 was drilled from the ramp, near its bottom, into the underlaying limestones. Chemistry of water at this hole also was sampled.

. Water flow temperature and chemistry at the Old Mine access the main overflow point of the aquifer.

2. Piezometric Evaluation

The logarithmic graph of fig. 6 indicates that transmissivity ranges are between 20 m^3/day and 30 m^3/day. It also show the existance of one or two negative barriers which showed up during the pumping test (one of then may be related to the East fault). The above conclussions should be regarded with reservation due to the karstic nature of the aquifer.

The recovery control test (fig. 7) give high transmissivity values (85 to 100 m^2/day). This was probably due to a larger thickness of saturated aquifer and a faster water flow through the main karstic conduits.

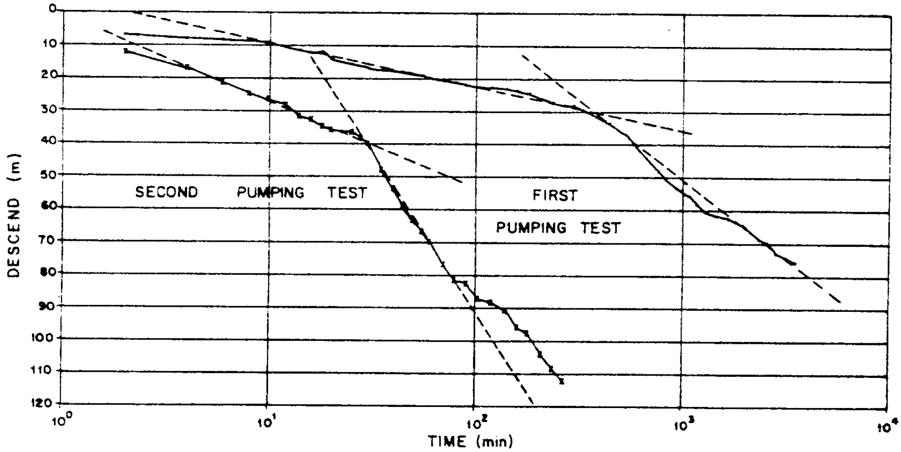


Figure 6. Descend - log.time curves during TH-1 pumping test.

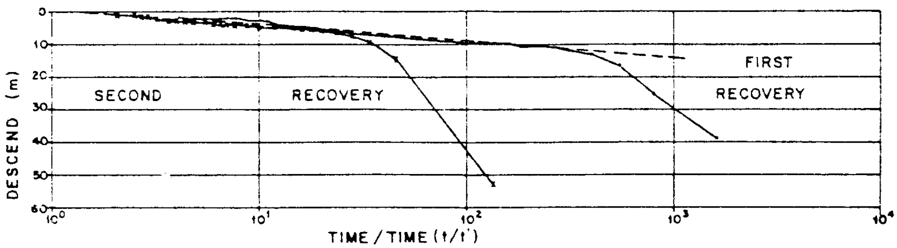


Figure 7. Residual descend - logarithm of t/t' during TH-1 recovery test.

3. Evolution of Water Chemistry

All the water assays showed calcium bicarbonated water as normal for a limestone aquifer.

The water pumped from TH-1 (fig. 8) had a maximum of disolved solids at the begining of the test, then a gradual decrease of disolved solids was observed. After 30 hours of pumping, dissolved solids increased again.

The interpretation of this variation is a follows: the water pumped initially is water from the area near the pump. This water has been captive for a long time and therefore it has dissolved more solids. As pumping proceeds, water from the upper part of the aquifer (south free aquifer) is pumped. This water has a low residence time and less solids. Afterwards, water from deeper zones flows in, and the amount of dissolved solids increases again.

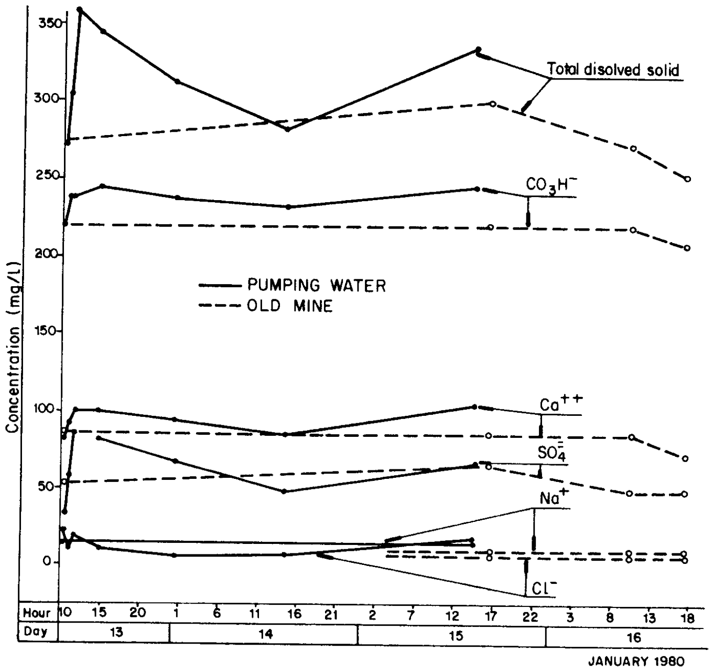


Figure 8. Evolution of water chemistry at TH-1 well and at Old Mine.

The chemistry of water from the Old Mine seems to confirm the above hypothesis (fig. 8). During the pumping test at TH-1, the mineralization of water from the Old Mine increased and decreased again at the end of pumping.

4. Evolution of Temperatures

The evolution of temperature during the pumping test (fig. 9) seems to respond to the same mechanism, with a decrease at the begining of pumping (free waters coming in) and a gradual increase afterwards (deep waters).

At the Old Mine (fig. 10), a similar variation was observed. This was probably related to snow melt water flowing in at a faster rate due to pumping.

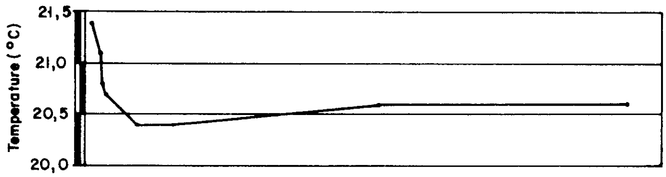


Figure 9. Evolution of water temperature at TH-1 well pumping.

5. Evolution of Water Outflows

During pumping, an important reduction of water outflow at the Old Mine was noticed (figs. 5 and 10). Similarly the water inflow to the bottom of the ramp and the amount of running water along the ramp decreased from 28 l/sec. down to 5 l/sec. (fig. 5).

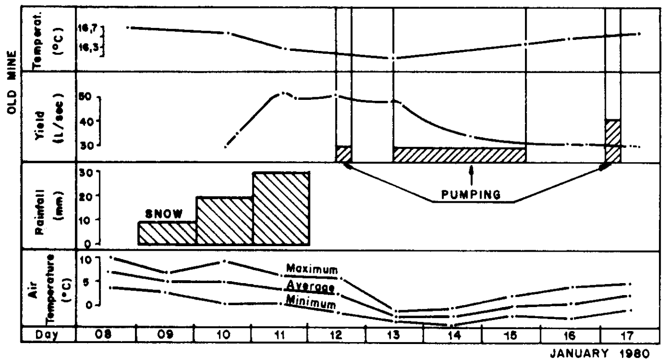


Figure 10. Evolution of flow and temperature of water at Old Mine, related with TH-1 well pumping and with rainfall and air temperature.

The main effects of and conclusions drawn from the test were:

- An important reduction (40% ?) of the water outflow at the Old Mine and of the water inflow to the ramp (75%). These points are located 500 m. and 20 m. from the well TH-1 respectively.
- A depression of the water table estimated in 2 m. for a total of 6850 m^3 of water pumped.
- A infiltration inflow estimated in 40 l/sec. with peaks of 200 l/sec.
-

. A clear influence of "negative barriers" over the aquifer which would be favourable for the drainage of the system.

HYDROLOGICAL CONTROLS

1. Controls

After the pumping test, effects of variation in the following parameters were examined:

. Rainfall (dayly).
. Start and stop time and working time of the ramp pumping system.
. Piezometry at TH-1 (daily).
. Water pressure and flow rate at T-46 diamond drill hole.

2. Pumping at the Ramp

The ramp dewatering is done by means of pumps installed near the bottom. These pumps are automated by level control switches. A separate pumping system is installed for emergency use.

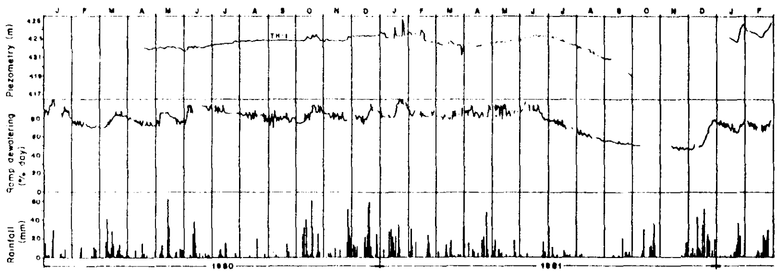


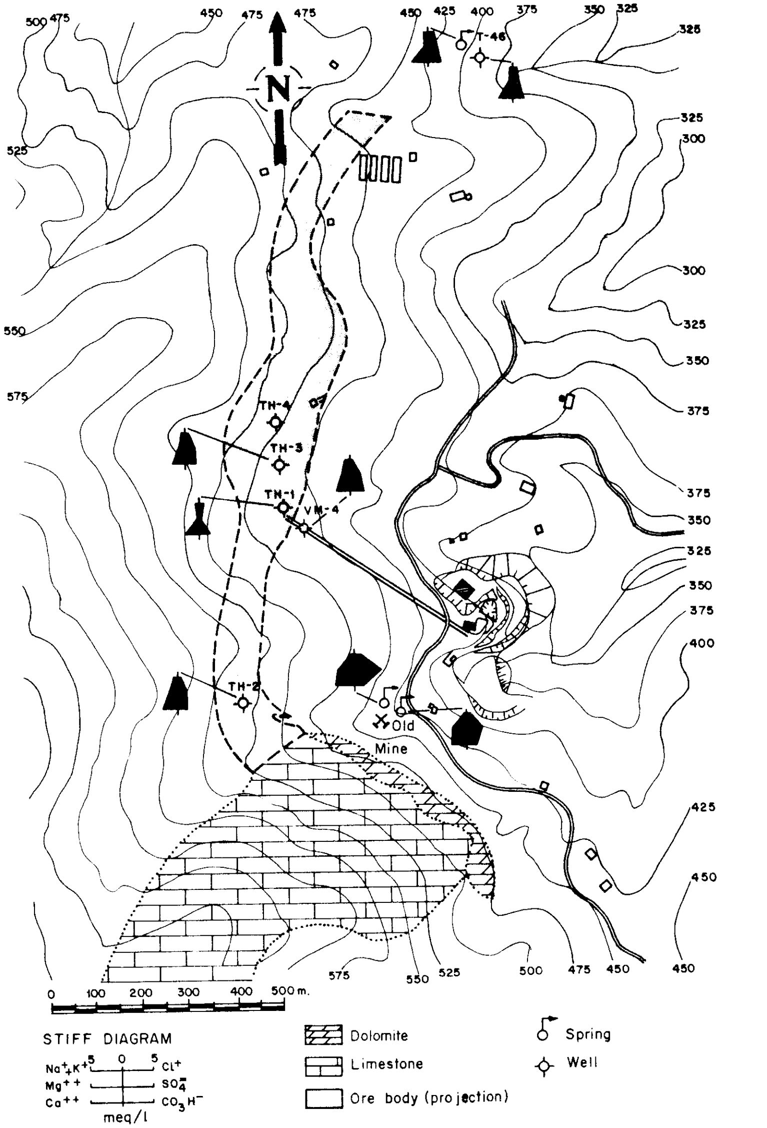
Figure 11. Hydrogram of piezometer level related with rainfall and ramp dewatering.

The average pumping rate under normal conditions is 20 litres/sec. and pumping time varies depending on water inflow. Fig. 11 show the pumping hours as a percentage of 24 hours, the rainfall and the piezometry at TH-1 well. From the observation of these graph the following comments are made:

. During 1980, pumping rate was relatively constant, while rainfall varied and the piezometric level trended upwards. This can not be explained from existing information.

. The dry season during 1981-1982 resulted in the depression of the water table at TH-1. This was due to a reduction of water reserves which was not compensated by recharge.

. The rainfalls from December 1981 to March 1982 caused an



igure 12. Hydrogeological wells and STIFF diagram for the main water
oints in the area.

increase of pumping time and a recovery of piezometric level but the water reserves were not totally recovered.

- Weekly variations reflect the effect of heavy rainshowers with a delay of one or several days. This delay is probably due to the poor hydraulic connection between the ramp and TH-1 well. The relationship between recharge (rain) and drainage (pumping) is anyhow evident.

It is remarkable that the difference in piezometric level between the bottom of the ramp and TH-1 well is over 85 m., being TH-1 only 20 m. away from the ramp. This fact proves that the hydraulic connection between ramp and TH-1 is very poor which is not surprising in a karstic media where water circulates through dissolution channels between low conductivity blocks.

PIEZOMETRIC AND PUMPING WELLS

Following the mine drainage program, three new wells were drilled using hammer drilling techniques. The program had started in June 1981 when hole TH-1 was drilled and was completed in the summer of 1982 with holes TH-2 and TH-3 designed for pump installation, and TH-4 equiped with piezometric pipe only.

Hole TH-2 was located at the southern limit of the ore body, close to the reefal limestone's outcrop and the Old Mine (fig. 12). TH-3 was collared near the centre of the ore body, an optimum pumping point for the future mine. TH-4 was drilled in the North of the ore body, cutting the section of the ore body which is planned for initial mining operations. Drill rig accesibility and geology were also considered for the location of the holes.

The initial water air-lifting using the rig's compressor produced flows of up to 80 l/sec and had a significant bearing in the system's piezometry as shows in figure 13, also affecting the artesian hole T-46.

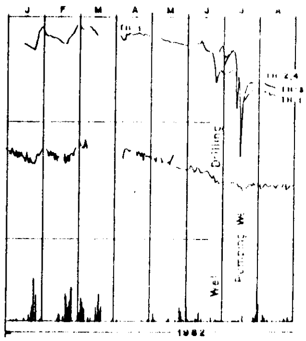


Figure 13. Hydrogram of piezometer level related with rainfall, ramp dewatering, air lift drilling and pumping test.

ARTESIAN HOLE T'46

This hole was drilled for exploration in the NE part of the ore body (fig. 12). It resulted in water flows which have been periodically registered (flows and pressures).

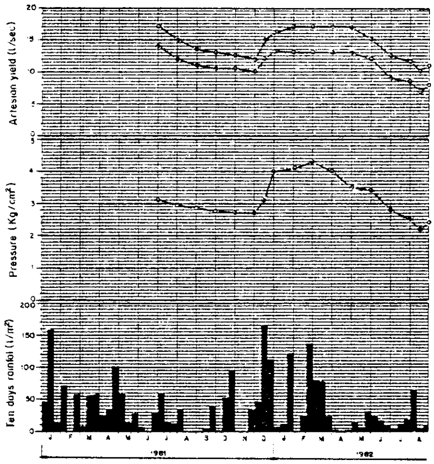


Figure 14. Hydrogram of T-46 hole showing internal pipe and total artesian flow, water pression and rainfall (by ten day periods).

Flow and pressure variations with time are shown in figure 14. The seasonal effect of rainfall is clearly evident. The maximum pressure of 4 Kg/cm^2 is obtained when the water table reaches its maximum level. At this maximum, an outflow of 17 l/sec. was recorded. Larger decrease in flow and pressure are observed in 1982 due to less rainfall and also to increased pumping and the air-lift water extraction during drilling of the wells (fig. 15).

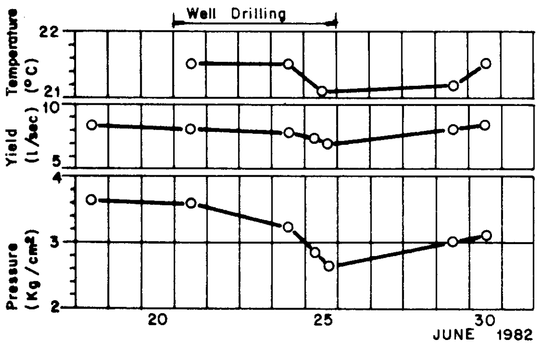


Figure 15. Effects of drilling of TH-3 over T-46 hole outflows (pressure, flows, and temperature).

All these effects were confirmed later by pumping tests in holes TH-2 and TH-3 showing a very high hydraulic conductivity in some areas of the aquifer (fig. 16).

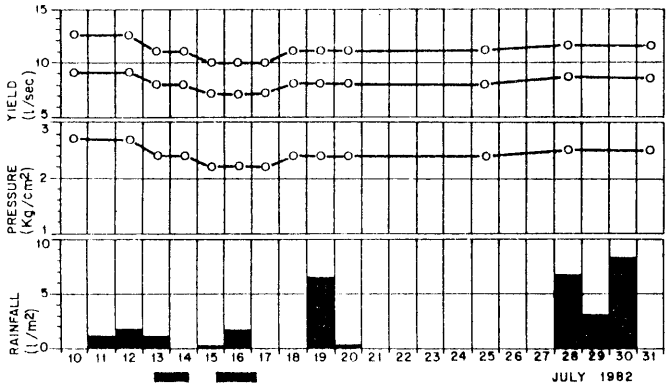


Figure 16. Effect of TH-2 and TH-3 pumping test over T-46 hole.

INVENTORY OF WATER SPRINGS

During the dry season (June-July of 1982) an inventory of springs in the vicinity of the ore body was prepared. Most of the springs were dry and the maximum flow of less than 0.5 l/sec was measured at the Old Mine.

Refering to the temperature, the water from the limestones aquifer range between 20º C and 21.5 ºC while water from the overlaying Urgonian formations have temperatures between 12º C and 14º C and flow rates below 0.1 l/sec.

Two different chemistries were observed. Karstic water, with low salinity (less than 285 mg/l total disolved solids) and calcium bicarbonates as the dominating anions, and water from the Old Mine with high salinity (330 to 410 mg/l) with high magnesium (from dolomites) and sulphate ions (from the oxidation of pyrites).

PHASE 2 - SECOND SERIES OF PUMPING TESTS

1. Piezometric Interpretation

This phase consisted in two pumping tests from TH-2, and TH-3 wells, the pump being located at 214 m. and 160 m. elevation above sea level respectively. All springs and water showings relative to the system were monitored.

The hydrogram for both tests is shown in figure 17. The first test, at TH-2 lasted 24 hours at a pumping rate of 36 l/sec. The total volume pumped was 3110 m^3, the pressure drop at TH-2 was very small and the level descend at TH-2 and also at the piezometers were almost linear.

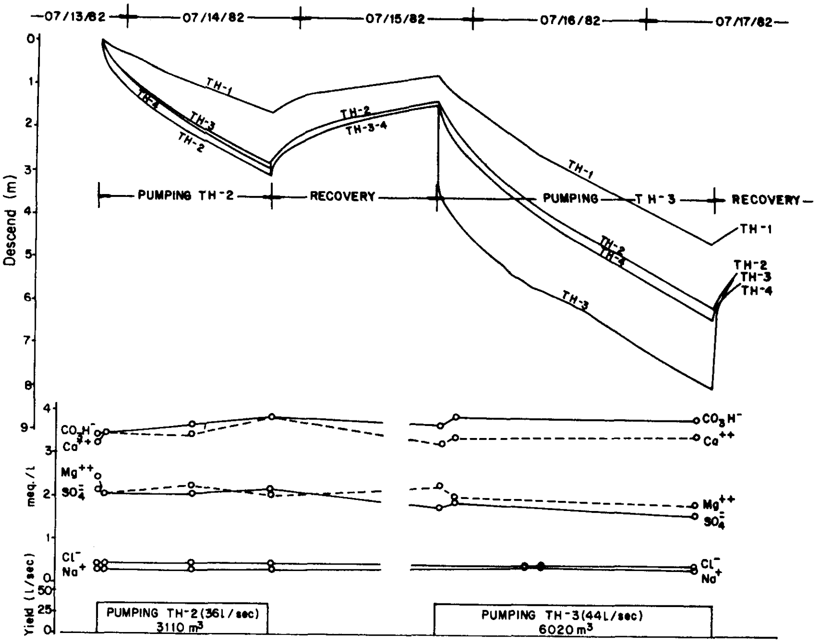


Figure 17. Hydrogram of pumping and recovery tests, and water chemistry evolution of pumping water (TH-2 and TH-3 wells).

The following conclusions were reached:

- The volume of aquifer emptied remains constant with depth.
- There are a very good hydraulic connection of TH-2 with wells TH-3 and TH-4 (531 m. and 719 m. away from the pump) and, as consequence, the water level is almost identical to that of TH-2.
- TH-1 is relatively separated from the other wells by a "hydrological barrier" which reduces the effect of pumping over the water table despite of TH-1 being the well closer to the pump (407 m).
- The logarithmic graph (fig. 18) confirms the existance of "negative barriers" which help dewatering by accelerating the descend of the water level.
- The best hydraulic connection is shown by TH-4 which is also the well furthest away from the pump.
- The level recovery at TH-2, TH-3 and TH-4 are almost

coincident over time, thus confirming a very high hydraulic connection (fig. 17). TH-1 recovery is much slower.

- A transmissivity of approximatively 100 to 300 m/day and a storage coefficient of 1 to 8 x 10 can be deducted from this test.

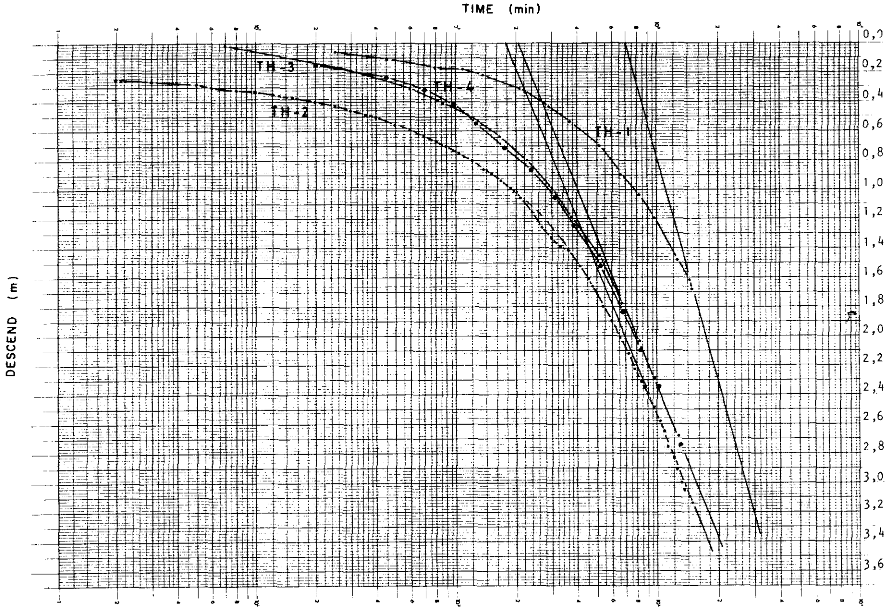


Figure 18. Hydrogram of descend - log. time, during TH-2 pumping test.

The second test (fig. 17) lasted 30 hours 15 min at a pumping rate of 44 l/sec. with a total production of 6,022 m^3. The results obtained confirm the aquifer characteristics observed in the previous test.

2. Effect of Pumping Tests Over the Ramp Dewatering

The ramp dewatering was clearly affected by the pumping tests at TH-2 and TH-3. A reduction on pumping time and an equivalent increase on idling time was observed for the ramp pumps (fig. 19). This effect continued after the tests were finished, reflecting the reduction of water reserves in the aquifer.

3. Water Chemistry

The assays on water samples taken during the pumping tests showed bicarbonated facies with high magnesium content and very low sodium. The ionic composition was very similar for all the samples, showing a high homogeneity of water composition over a large part of the aquifer.

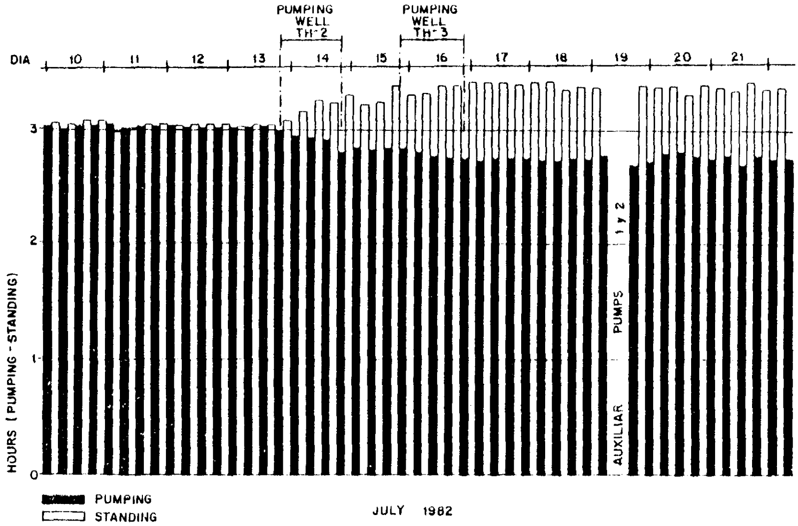


Figure 19. Effects of TH-2 and TH-3 pumping tests, over pumping and standing at the ramp's face.

A continuous and progressive decrease of the ratio SO_4/HCO_3 was observed during the test. This can be explained by the bicarbonated composition of the water and the decrease with depth of the sulphate ions produced from the oxidation of pyrites.

CONCLUSIONS

As a result of phases 1 and 2 of this investigation, the following conclusions may be stated:

- The piezometry of the aquifer shows variations of over five metres resulting from the ramp drainage and the recharge due to rainfall. Larger variations may be expected once the aquifer drainage is started.
- The overall recharge rate during the time period observed is lower than the water losses due to pumping and water outflow at T-46; thus, the aquifer is loosing reserves slowly.
- Ramp drainage and T-46 outflows have reduced water exit through the Old Mine workings to a minimum. The pumping tests have further reduced outflows at the ramp, T-46 and Old Mine.

- The temperature and chemical composition of water are slightly different from other aquifers in the area.

- The ramp and TH-1 well are located in a zone which is not well connected with the main circulation ways in the aquifer. Fan drilling from the ramp down into the limestones would increase water inflow to the ramp, thus accelerating drainage.

- The aquifer presents water ways with extraordinarily high hydraulic connection between low permeability blocks, as shown in the idealized model in figure 20.

- The aquifer is limited by "negative barriers" which facilitate its drainage by pumping at moderate rates (about ten liters per second). As a result of drainage, induced recharge may appear and in that case pumping rates of 100 l/sec. might be required.

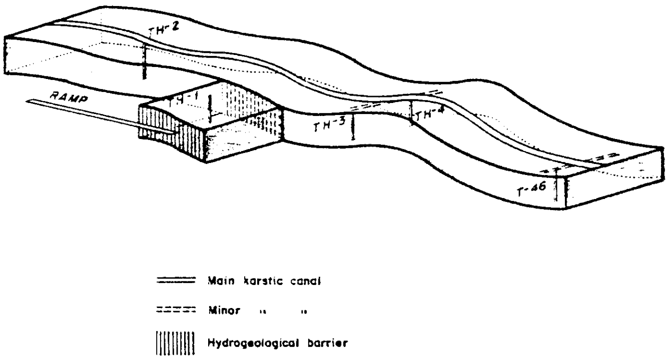


Figure 20. Idealized model of karstic connections and barriers.

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