WATER INFLOW PREVISION IN THE SANTA BARBARA PROJECTED MINE (LEON, ESPAÑA)

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ABSTRACT

One of the valiable that currently determine the new mines feasibility is given by the water volume needed to be pumped during explotation, acording to the high energy prices. The possibility of working the Santa Bárbara Pb- Zn deposit in terms of underground works is restricted by a unfavorable hidrogeologic position. In fact the mineralization lies within a limestone-dolomite level which is crossed by an important river just a site very mear to the vertical of the future mine that will be developed at a 400 m depth below the river. Given this situation, a comprehensive hydrogeological study has been carried out, which apart from conventional techniques (pumping test, logging, rock fracturation, etc.) also includes some others that are actually new in carbonated terrains, such as water injection test using a straddle-packer sistem in boreholes of small diameter and great depth. By there means a hydrodynamic caractherization of the carbonated massif both at the surface and in vertical, has been achiered. The study has allowel to calculate the water inflow in the diferent explotation etapes by mean of a mathematical model prepared for the ore deposit.

INTRODUCTION

The Santa Bárbara lead-zinc deposit is located in the León Province of Northwest Spain (fig. 1). The mineralization was emplaced in solution cavities at the top of a Cambrian carbonate unit (the Vegadeo limestone) intercalated in layers of schist. This limestone layer now occupies a subvertical position on the south (reverse) flank of a large anticlinal structure.

Reconnaissance was carried out by a group consisting of the Sociedad Minera y Metalúrgica Peñarroya-España and by the Empresa Nacional Adaro de Investigaciones Mineras in the context of the Spanish Government's plan for the supply of mineral raw materials.

As soon as the possibility of underground exploitation of the deposit was suggested by mineral reconnaissance work, a study was carried out with the aim of identifying the hydrogeologic problems associated with eventual mining. -

The precise aim of this study was to evaluate the discharge representative of dewatering for the future mine, located in an unfavorable hydrogeologic position within a partially karstified carbonate assemblage at a depth of 400 m below the Rio Sil which obliquely cuts the structure.

Study was carried out in two phases. A preliminary phase identified the existence of a limestone aquifer hydraulically associated with the Rio Sil. The decision was therefore taken to carry out a second phase of exhaustive study aiming to determine the structural and hydrodynamic characteristics of the rock mass and evaluate the dewatering discharge for the mine at various stages of exploitation with the aid of a mathematical flow-simulation modd. The present report is concerned with this second stage.

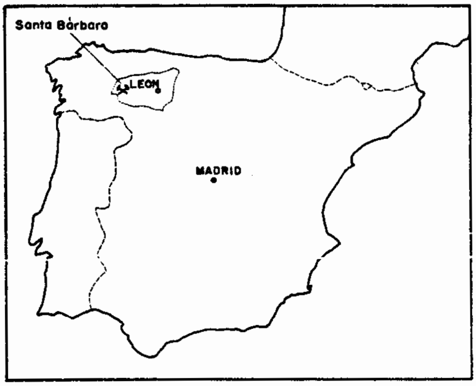
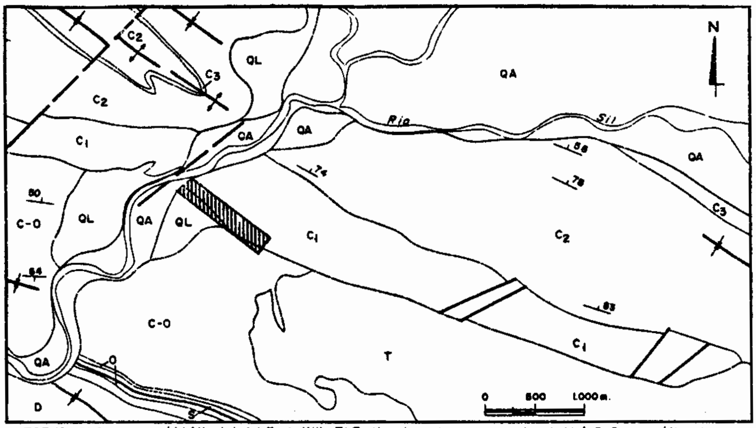


Fig. 1: Location map

GEOLOGIC SETTING

The Santa Barbara prospect is located on the vertical limb of a large anticlinale. The top of the Cambrian limestone sequence is dolomitized and silicified; the silicified facies are locally mineralized. Cambro — Tremadoc schists stratigraphically overlie the limestone sequence and bound it to the south. Detailed geological study and mapping have been completed by J-L HERMOSA.



LEGEND: Q: Quaternary (A: Alluvial, L: Foot Hill. T: Tertiary (conglomerates, sand and silts). D: Devonian (limestones, shales). S: Silurian (shales). O: Upper Ordovician (limestones). C-O: Middle-Upper Cambrian-Lover Ordovician (black shales, quarzites sandstones). C_1 : Middle Cambrian (limestones and dolomite. Vegadeo serie). C_2 Lower Cambrian (green shales and sandstones). C_3 : Lower Cambrian (sandstones) Mineral deposit setting.

Fig. 2: Geological regional map (according to MAGNA, 1/50.000)

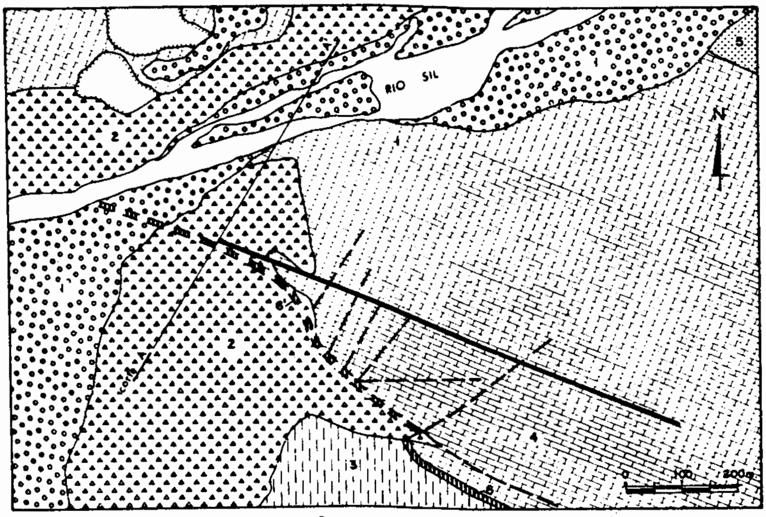


Fig. 3: Detailed geological map

LEGEND. 1: Alluvial. 2: Foot Hill. 3: Black shales. 4: Vegadeo limestones and dolomites. 5: Green shales. 6: Ore body. 6': Ore body surface proyection.
--- Important fracture. ▬ Aproximated surface proyection of the future mine.

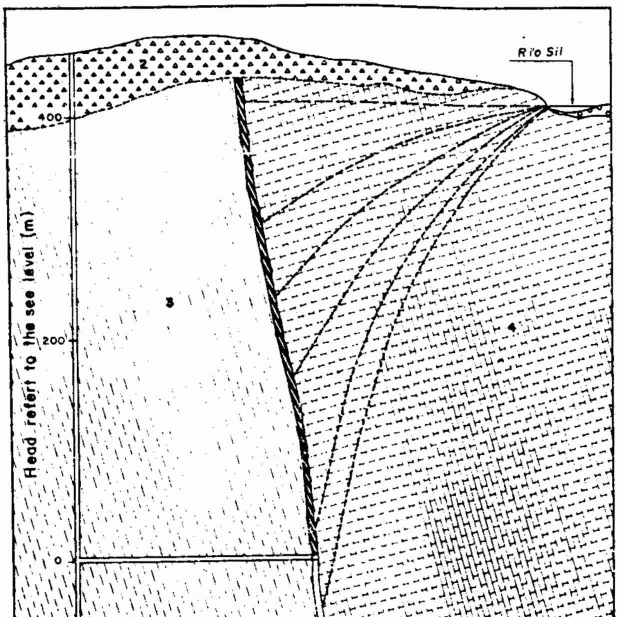


Fig. 4: Simplified hydrogeological - cross section(A-A')

LEGEND

--- Present position of the phreatic level.

Futurs positions of the phreatic level under the mine drainage effect

Futur explorations minning works.

The average orientation of the structure is N 120° E.

The anticline is transversally cut by the Rio Sil, which drains the Tertiary Ponferrada basin. The Rio Sil and its tributaries reach the Santa Barbara gorge, the downstream part of which is formed by transversal impervious - schists. Upstream of the schists a shallow karst develops in close relation to the river bed. In the downstream part of the gorge, this karst has the same base level as the river, which prevents it from developing at depth.

A paleo-karst of the same type is clearly visible in and around a quarry located on the right bank of the gorge, some 20 meters above the present level of the river. This paleo-karst has two characteristics: it is wide open but develops only in the vicinity of the older river bed. As the morphological conditions at the time were quite similar to present-day conditions, it is possible to infer the present-day extension of the karst.

All the water tests carried out in boreholes, on the left bank confirm the following hypotheses:

1.- There are no open karstic conduits. Fractures are encountered in boreholes on the Santa Barbara hill and mainly develop over several tens of meters below the water table (and probably also above the water table);

2.- The water table is at the same level as the river, which implies a very conductive passage way below and beside the river bed.

The open conductive fractures do not display a transmissivity of sufficient magnitude to explain this.

DESCRIPTION OF IN-SITU INVESTIGATIONS

In-situ investigations were designed to determine the threedimensional distribution of permeability and storage coefficients for the rock mass within which the projected mine is located, the aim being to integrate this information within a computerized flow model enabling determination of water influx into the mine.

Preliminary investigations based on surface observations and pumping tests in a shallow borehole drilled in the limestone very near the Rio Sil alluvium demonstrated the very high permeability of the upper part of this limestone. Simplified calculation based on the hypothesis that the high permeability is constant at depth shows that water influx into the mine would be about 0,5 m^3/s, a figure which is economically inacceptable. This high permeability is due to fracturing in the limestone and to the presence of solution cavities.

It was thought that the fractures probably tend to close at depth due to the effects of stress, thus reducing the permeability. It is well known that solution phenomena develop mainly in the unsaturated zone and in the zone of water-table fluctuation, i.e. considerably above the level of the future mine. The hypothesis of decreased permeability with depth could thus be regarded as realistic, but needed to be checked by in-situ measurements. Such measurements were also necessary in order to calculate water influx into the mine.

The in-situ measurement program designed to satisfy the above objectives included:

1.- A survey of fracturing, both in borehole cores and in outcrops distributed over the area as a whole. The purpose of this survey was to determine the prodominant fracture orientation (and thus the directions of anisotropy in the permeability), to delineate zones of maximum fracture density, and study their relationships with large fractures, and to study variations in fracture density and solution phenomena with depth.

2.- Additional pumping tests in shallow boreholes at various distances from the river, to confirm permeability values in the upper part of the limestone.

3.- Water tests in 4 small-diameter cored boreholes, to a depth of more than 600 m to determine the vertical permeability log. Determination was made using two techniques: (1) water injection tests using a straddle-packer system and (2) determination (using micro-current meter) of the profile for axial flow velocity during pumping. These tests were preceded by detailed geophysical logging in order to detect water-bearing fractures, weathered areas, etc.

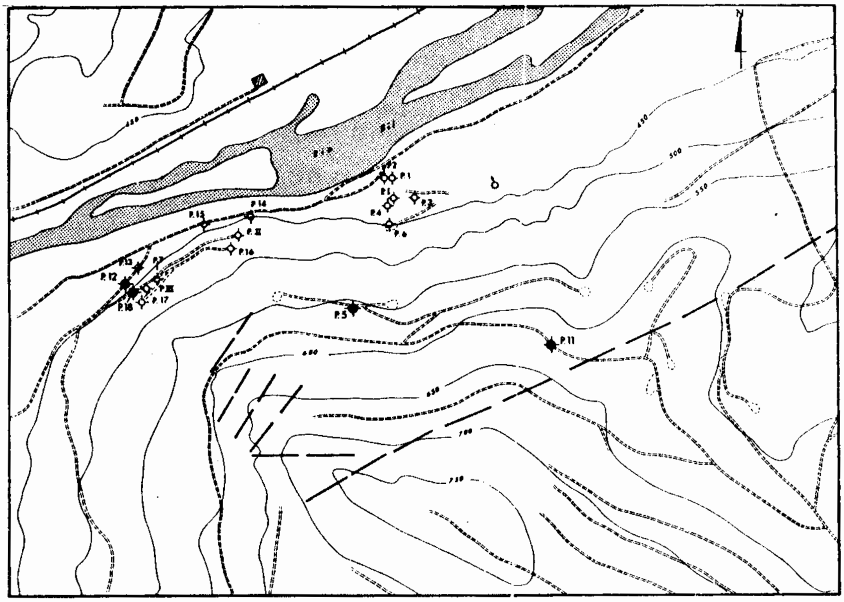


Fig. 5: Location map of hydrogeological boreholes

STUDY OF FRACTURING

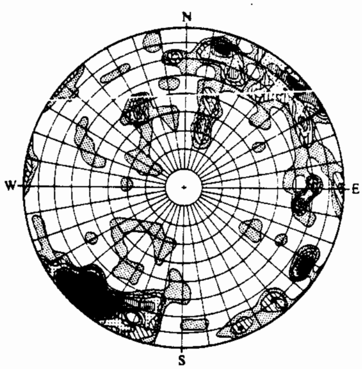
The Santa Barbara area has been subjected to fracture logging in most existing outcrops and in drill holes. The term fracturing refers to all discontinuities in the massif, particularly stratification planes and joints.

Almost 1.800 discontinuities distributed between about 50 measurement sta tions were identified in the limestone portion of the massif.

These data were then subjected to computer processing, station by station and as a whole. The following documents were produced:

1.- Circular diagrams (Schmidt projections, lower hemisphere) for the poles of the various planes identified, distinguishing between stratification planes, faults with clayey joints, fissures, and joints.

2.- Diagrams showing the poles of isodensity curves, thus making it possible to identify tha major sets of discontinuities represented by clusters of poles.



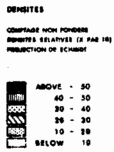


Fig. 6: Schmidt diagram (faults and joints)

This analysis reveals a system of stratification planes striking 120° N and dipping 75° E, a set of fissures striking 25° N and dipping 70° W two sets of joints striking 30 and 60° N and dipping 70°W and 40° E respectively, and a set of faults with clayey joints strking 130° N and dipping 80° E.

The system of faults with clayey joints cuts the stratification planes. Figure 6 shows the isodensity curves for the poles representative of this fault system.

MEASUREMENT OF HYDRODYNAMIC CHARACTERISTICS OF ROCK MASS IN SHALLOW WELLS

Study of the hydrodynamic characteristics of the surface limestone layer was carried out by pumping tests in two series of boreholes: (1) producing well PII and piezometers P14, 15 and 16, and (2) producing well PIII and piezometers P7,12,13 and 17 (fig. 5).

These tests complement those completed in well PI during the first phase of study. All the boreholes penetrate the saturated zone over a a thickness of between 90 and 100 m. Abnormal transport of solid particles was observed during development of well PII corresponding to washing out of a fracture zone and not to development of the well itself. Two pumping tests operations were therefore carried out at the same discharge, separated by an intermediate period during which vigorous washing of the unconsolidated fill zone was carried out. The first pumping operation was interpreted using a model specific to fractured media, producing a mean transmissivity of 1.3×10^{-3} to 4×10^{-4} m^2/s and a storage coefficient of 1.5×10^{-2} to 5.5×10^{-4}. The results of the second pumping operation in well PII correspond to a Theis model, with mean transmissivity values of 3×10^{-3} m^2/s a storage coefficient of 3×10^{-2} to 5.5×10^{-4}. The transmissivity thus increases by a factor of between 3 and 5 from one test to another. This is due to the fact that pumping causes washing out of the occluded fractures.

The following conclusions are drawn from the tests completed:

1.- Fracture zones with an uncemented filling exist within the aquifer and may cause - problems during exploitation of the mine.

2.- The pumping test operation carried out in well PI after washing out of the fracture zones has been reinterpreted and corrected. The results obtained are consistent with those for the first test on well PII (T=2.1 to 7.6x10^{-4} m^2/s; S=1 x 10^{-3} to 6x10^{-4}.

3.- In the case of well PII, the values assumed for the hydrodynamic characteristics of the ground are those deduced from the first test. Two pumping operations were also carried out in well PIII but these were not interpreted due to the excessively low permeability of the - rocks intersected.

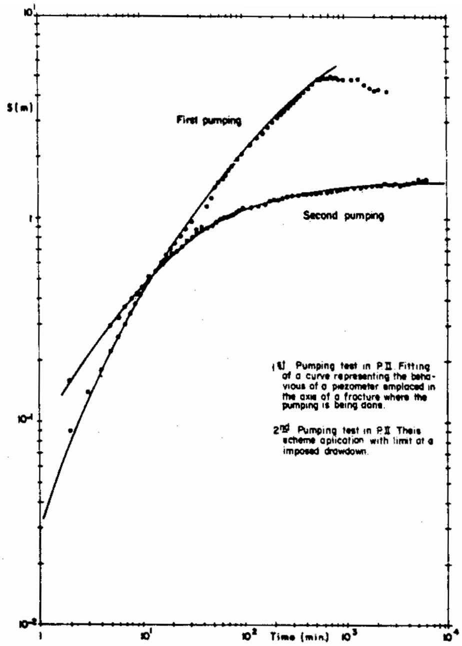


Fig. 7: Drawdown evolution in piezometer P-14

Figure 7 illustrates the influence of washing out of the fractures, as described above, on drawdown curves for piezometer P14.

DETERMINATION OF VERTICAL PERMEABILITY PROFILES

Permeability profiles for vertical boreholes drilled entirely in limestone facies (P5, 11 and 12) were completed from the results of test injections (10 tests per borehole) complemented by measurements of water flow using a micro-current meter and total air-lift test pumping. In the case of the inclined borehole (P18) which reaches the aquifer layer, intersects the mineralized zone and penetrates the black schists, only test injection results were used for determination of permeability. Figure 5 shows boreholes location.

Before describing the results obtained, a brief description is given of the method employed:

1.- Principle and method of interpretation: the test involves injecting water into a borehole interval between the hole bottom and a single packer or into an straddle-packer system; this interval is referred to as the "test interval" or "injection chamber". Injection is made at a constant discharge, and the pressure is measured after it has stabilized. Discharge-pressure measurements are made by steps as the pressure rises and then falls. For all injection pressure (ΔP) and stabilized discharge (Q) measurements it is possible to calculate the permeability using the following formula valid for a permanent horizontal flow regime: k (m/s) = 1.85 x 10^{-5} $\frac{Q}{L.\Delta P}$, where L is the height of the test interval, Q being expressed in l/min and P in m of water. In an ideal case, Q=f(ΔP)forms a straight line whose slope is proportional to k. However, very often, the curve Q=f(ΔP) not only is not a straight line, but also is not identical for increasing and decreasing rates, indicating irreversible fracture behavior. Each curve corresponding to a tested interval should be carefully examined in order to determine the behavior of the medium and to select the corresponding permeability.

2.- Test technology: the measurement array shown opposite comprises the following main components.

(a) The TAM packers were modified to enable inflation by a separate line. The sleeve diameter is 2 5/8" and the effective length 0.80 m. In the case of the present tests, the packers were inflated using fresh water at an operating pressure of between 40 and 60 bars.

(b) A multifunction distributor was placed above the packers. Depending on its position, this distributor enables inflation and deflation of the packers, water injection into the test interval, and drainage of the pipe string.

(c) The well head comprises an injection head connected by a high-pressure flexible hose to the discharge meter panel.A lock chamber allows a logging cable and a lifting system incorporating a dynamometer(for positioning of the distributor) to pass without affecting the water tightness of the head.

(d) An injection pump incorporating a hydrostatic converter facilitates continuous adjustment of the discharge from 0 to 30 l/mn for a maximum pressure of 30 bars.

(e) A discharge and pressure measurement instrument is connected to a recording device.

The accuracy and reliability of the apparatus described makes it possible to determine very low permeabilities of about 10^{-10} m/s.

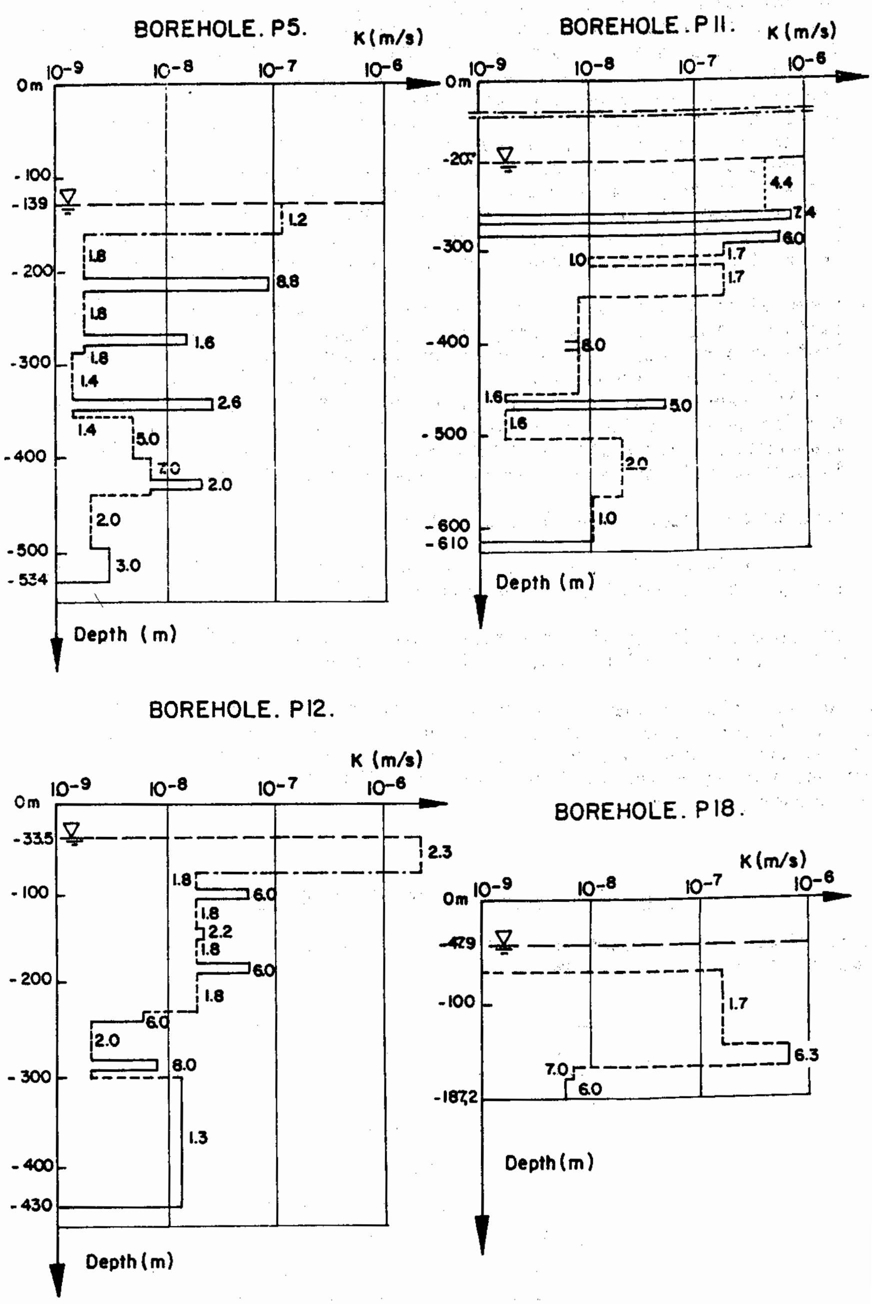
.- Criteria employed in selection and location of test intervals: in order to define the permeability profile for the rocks 10 tests were completed in each of the three vertical boreholes and 4 tests in the inclined borehole. These tests were carried out either by injection between two packers or by injection between the borehole bottom and a single packer.

In the first case, the aim was to detect structural features such as faults, substantial fracturing, or karst structures. The length of the interval, selected as a function of the average thickness of features encountered was 10 m for all tests. These selection criteria were drawn up from the results of logging carried out in the boreholes and confirmed by examination of borehole cores.

Injection between the bottom of the hole and a single packer was carried out in order to test a homogeneous geologic unit with a substantial thickness. This method is necessary in all cases in order to determine the nature both of the lower part of a given borehole and of the borehole as a whole.

Generally speaking and for each interval tested, nine discharge over pressure measurements are sufficient to provide a curve characteristic of

Fig. 8: Synthetic permeability profiles



test injection.

4.- Interpretation of results: as a general rule, the permeability assumed for each interval is calculated from the first steps of rising pressure, i.e. at the points corresponding to lowest hydraulic pressure. After examination of the recordings made throughout testing, the steps selected are those for which satisfactory stabilization of the injection pressure was obtained, discharge being maintained at a constant level throughout the measurement step. Where the behavior of the test zone is linear and reversible, the permeability calculated from data for the first steps is roughly equivalent to that determined from the discharge steps. However where the behavior of the test zone is reversible but not linear the permeability is calculated for the first step(s) of rising pressure, before the discharge-hydraulic pressure curve loses its linearity.

5.- Permeability profiles for the four boreholes tested: synopsis of the results obtained during the program of hydrogeologic reconnaissance on the Santa Barbara deposit resulted in preparation of a permeability profile for each of the boreholes tested (P5, 11, 12 and 18). Figure 8 shows a graphic representation of these profiles, contrasting the results obtained for test injection with those for air-lift pumping and water-flow measurement using a micro-current meter. In the case of borehole P18, only test injections using a single valve were carried out.

The results described above clearly show that:

1.- The upper layer of the rock mass below the hydrostatic level has a relatively high permeability of between 1 x 10^{-7} and 3 x 10^{-6} m/s.

2.- The permeability of the rock mass decreases considerably with depth, rarely exceeding 10^{-8} m/s outside fracture zones.

The vertical distribution of permeability in the rock mass has been calculated down to zero level in the case of the first three boreholes, the aim being to provide the components necessary for evaluation of the effect of underground mining on the local hydrogeology. This evaluation is discussed in the following section.

WATER INFLOW AT MINING WORKS. MODELLING

A three-dimensionnal numerical model has been calibrated on injection test permeability values as follows:

K (m/s)	Facies
1.10^{-4}	Alluvial plain
1.10^{-5}	Foot hill
6.10^{-9}	Schists (surface)
1.10^{-9}	Schists (unfractured)
2 to 3.10^{-6}	Limestones (unfractured)
10^{-8} to 10^{-7}	Limestones (massif)

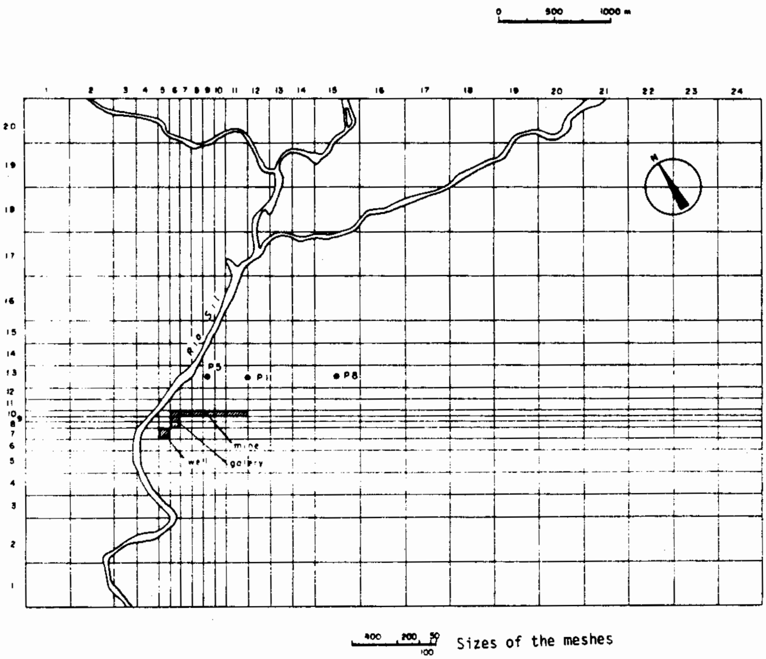


Fig. 9.A : Santa Barbara : schematic situation of the model

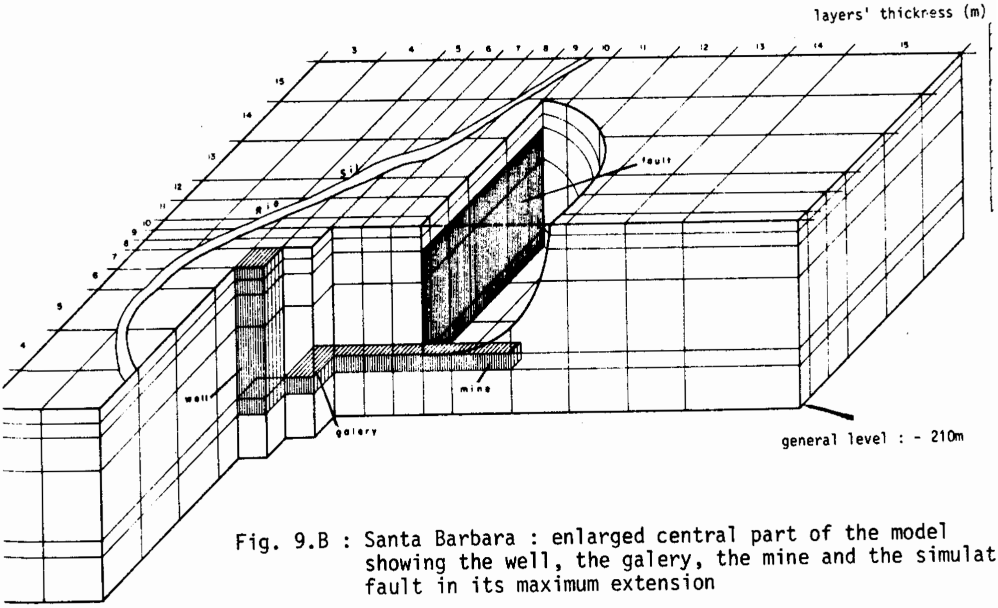


Fig. 9.B : Santa Barbara : enlarged central part of the model showing the well, the galery, the mine and the simulat fault in its maximum extension

The rock mass simulated is located between the Rio Sil (N and NW), the schists (S and SE) and an artificial boundary to the east. The model comprises six horizontal layers, each characterized by a constant permeability value. The present level of the water table is in the top layer;the mine will be located in layer 5 which is 60 m thick.

The horizontal grid ranges from 50 x 100 m to 400 x 400 m. The fully developed mine will comprise a shaft, air access gallery and the mine itself,occupying six panels. Five are represented by 50 x 400 x 60 grids and one by a 50 x 200 x 60 grid.

Four main simulations have been undertaken. The first takes account of a slightly fractured rock mass, in which permeability values are strictly deduced from injection tests and correspond statistically to the mean.In this case, the total discharge which has to be pumped from the mine is stabilized at around 40 m^3/h after 50 months, and depletion of the water table is slight, remaining within the top layer of the model. The rock mass remains saturated around the gallery and the panels.

The three other cases simulate partial drainage of the rock mass, which contains a fracture plane. This fracture plane is in fact regarded as a fractured compartment 50 m wide with a permeability equal to the highest spot permeability value 5×10^{-6} m/s encountered during injection tests in the limestone. The extension of this fracture plane progressively increases over the three simulations, reaching a maximum extension shown in the figure. Given this pessimistic hypothesis of fracture development, the pumped discharge will evolue from zero to 25 m^3/h during the first 21 months of exploitation before reaching the fractured compartment. It will subsequently increase rapidly to a maximum of 125 m^3/h indicating partial drawdown in the compartment, and will stabilize at less than 110 m^3/h after the 20th month.

CONCLUSIONS

The study completed makes it possible to evaluate the discharge of water influx to be expected in the future mine at Santa Barbara, and to demonstrate that this does not represent on obstacle to exploitation of the deposit.

This positive result was only reached as a result of permeability measurements in deep boreholes, at depths where the limestone is considerably less affected by solution phenomena than in surface layers. If calculations had been based on permeabilities deduced from tests carried out in shallower wells, the result would have been substantial overestimation of water influx.

Caution should nonetheless be exercized during exploitation. The study completed shows that the rock mass is intersected by numerous fractures, some of which are filled with unconsolidaded material and are likely to clear, giving rise to localized water or mud influx. In order to provide protection against such phenomena, reconnaissance boreholes should systematically be put down in advance at the site of future underground workings.

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