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Mining-Hydrological Characteristics of the Underground Copper Mine of Neves-Corvo, Portugal

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ABSTRACT

During the development of the Neves-Corvo Underground Copper Mine, since 1981, inflow of water has been encountered in the mine workings, which consist of a ramp from surface 5 km long, a shaft 575 m deep and access crosscuts through the massive sulphide orebodies of Neves, Corvo and Graça, which are three of the four known deposits up today. Mine-hydrological studies have established the main characteristics of the hydrological system and its evolution in space and time. In a geological setting of low permeability rocks of Paleozoic age, tectonically affected by thrusts and faults, this has involved consideration of the relation with surface and ground water as a result of mine dewatering processes. The hydrological systems are described and summarized in this paper together with the techniques employed to study their origin and evolution, namely hydrochemistry, thermometry, piezometry and isotopic tracers.

1. INTRODUCTION

The Iberian Pyrite Belt (IPB) (figure 1) is an important metallogenetic province extending over an area of 250 km x 40 km between Portugal and Spain, with several occurrences of Paleozoic polymetallic sulphide deposits. Neves-Corvo, remarkable because of the high grade of its cupriferous ore zones, reinforces the position of the IPB as the largest ore-mining district in Western Europe.

The discovery of Neves-Corvo deposits in 1977 (1), is a case-history result of a methodology integrating systematically Geological, Geophysical and Geochemical data that resulted in the intersection of ore at depths between 300 m to 700 m below surface.

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(1) The discovery was made by an exploration consortium of the Portuguese State Company SMS (Sociedade Mineira de Santiago, at present named EDM, Empresa de Desenvolvimento Mineiro EP) and the Frenchs SMMP (Societé Miniere et Metallurgique de Peñarroya) and BRGM (Bureau de Recherches Gèologiques et Minières). SOMINCOR (Sociedade Mineira de Neves-Corvo S.A.) was formed by the consortium in 1980. In June 1985 RTZ Metals Ltd (part of Rio Tinto-Zinc Group) acquired the 49% of SOMINCOR which had been held by SMMP and BRGM.

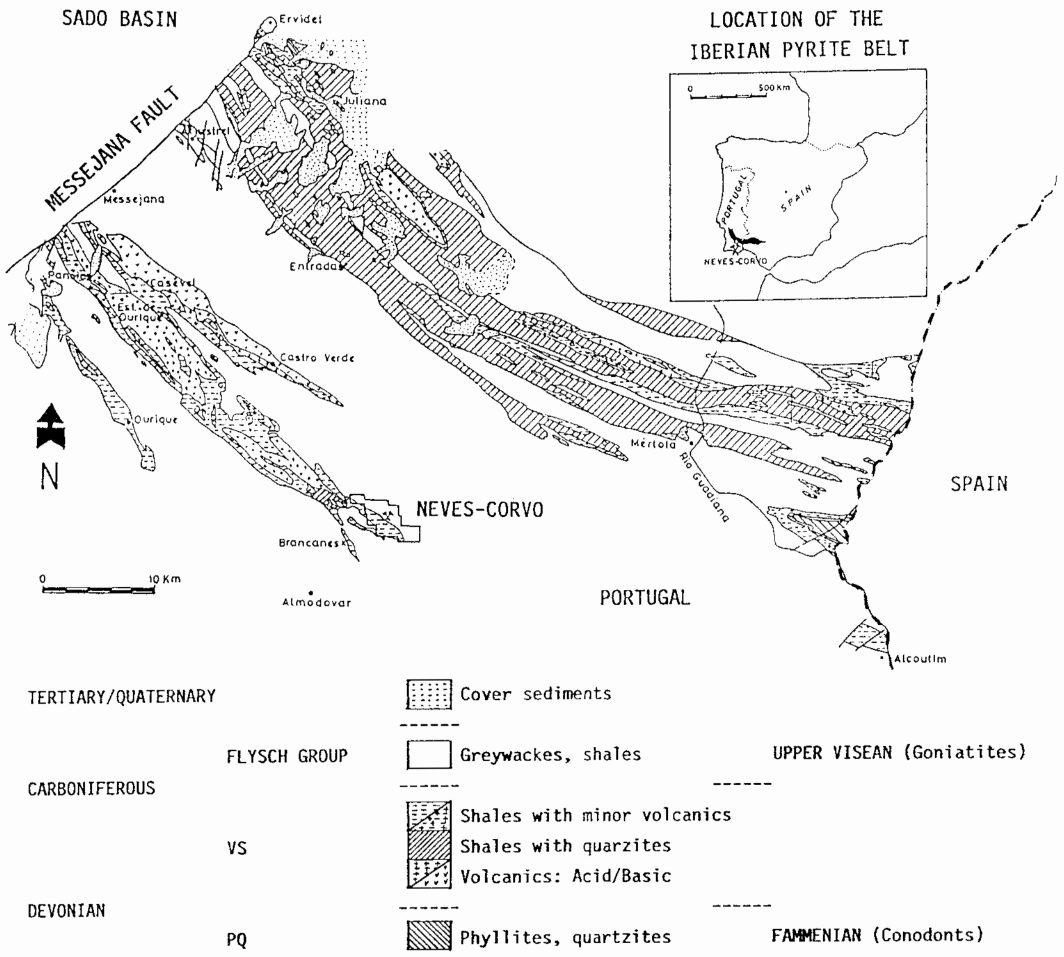

Figure 1. Geological map of the Baixo Alentejo, Portugal.

After the discovery, a first phase of surface drilling was developed as part of an exploration programme of the four massive sulphide orebodies of Neves, Corvo, Graça and Zambujal. At the same time a preliminary hydrogeological study was made in order to know the ground water behaviour and to obtain quantified data that could assist in the solution of the problems related with water during the mining period (BRGM, 1982; Feuga et al., 1984).

A second phase, since 1981, of development of the underground infra-estructure and parallel evaluation programme, revealed from the hydrological point of view a more complex system of inflow of water encountered in the mine works. This necessitated the planning of a more detailed study leading to an interpretation of the hydrological system, its likely evolution with time, and its impact in the areas of mine development and enviromental control.

The possibility of reduction of the inflow of water in the mine works, dewatering of early stoping areas and the control of potential acid water production are the targets to reach in a geological setting of low permeability rocks, mainly volcanic-silicious, tectonically affected by thrusts and faults.

2. GENERAL GEOLOGY

The IPB presents a sucession of formations ranging from Devonian to Carboniferous age that were deposited in the South Portuguese Zone (SPZ), one of the major segments of the Hercynian Orogeny (Carvalho et al., 1971; Ribeiro et al., 1979).

Three lithostratigraphical units are identified in the IPB (figure 1):

* The Phyllite-Quartzite Group (PQ) (Schermerhorn, 1971), is composed of thick indiferentiated phyllites containing, at the top, a level of quartzites commonly associated with limestone lenses that were aged Fammenian with Conodont fauna (Boogard, 1967).

* The overlying Volcanic Sedimentary Complex (VS), that has a gradational contact with the PQ Group, is characterized by the influence of the volcanic activity, presenting a heterogeneous variety of exclusively volcanic, sedimentary and mixed types of lithofacies. The various sulphide ore deposits encountered in the IPB are placed within the VS Complex, in association with acid volcanic events.

* The third lithostratigraphical unit is the Flysch Group, which is conformable with the VS Complex. The composition of the Flysch Group is a monotonous alternation of graywackes and shales with rare conglomerates. The base of the Flysch Group, in the Neves-Corvo area, is of Upper Visean age (Goniatite fauna) (Oliveira, 1983). However in the South Portuguese Zone it ranges between Lower Visean to Namuro-Westephalian, in association with a large scale subsidence propagated from NE to SW, in the opposite direction to the main explosive, felsic and subaereal or shallow submarine volcanic activity, indicating a diachronism between the VS Complex and the Flysch Group (Carvalho, 1976; Ribeiro et al., 1979).

The Hercynian Orogeny affected the IPB at different tectonic phases, resulting in the oriented structures seen at surface (figure 1). In the early phase it takes the form of low angle thrusting and gentle folding followed by the main phase of major folding, thrusting and the development of regional cleavage. A weak crenulation cleavage is related with a third post-methamorphic phase.

Major faulting associated with a late tectonic phase consists mainly of sets of NW, N, and NE trending sinistral and dextral wrench faults. The Messejana Fault (figure 1) is a very important sinistral fault (up to 3 km horizontal displacement) limiting the Tertiary Sado Basin, to the north, that forms most of the recent cover sediments seen at surface. The Messejana Fault and some of the other wrench faults were reactivated since the pre-ore period, explaining the subsidence on the SPZ. The tectonic deformation was acompanied by a low grade methamorphism up to lower greenschist facies (Schermerhorn, 1975; Munhã, 1979).

3. LOCAL GEOLOGY

The Neves-Corvo area presents the same geological characteristics as described before for the IPB in general.

In fact the oriented NW structure that includes the area of Neves-Corvo deposits is defined as the major Panoias-Castro Verde anticlinorial structure (figure 1) exhibiting in its core a relatively extended outcrop of the PQ Group, bordered by all types of formations of the VS Complex. The main outcrops are the cover sedimentary graywackes and shales of the Flysch Group (figure 2).

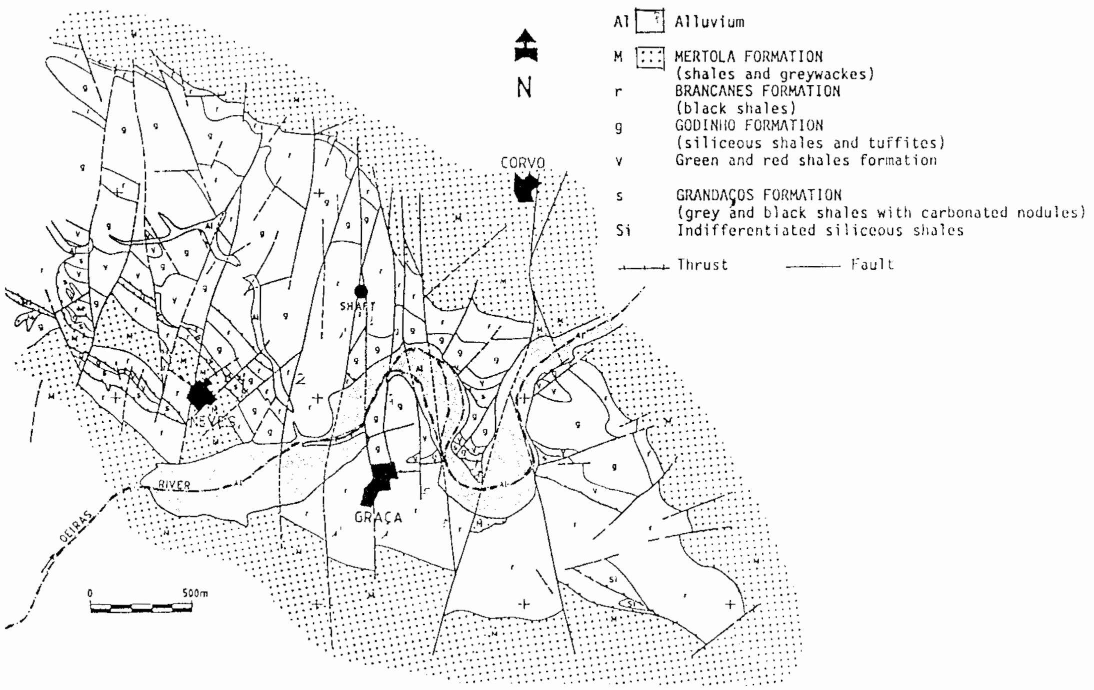

Figure 2. Detailed geological map of the mine area.

From base to top the stratigraphic sequence (figure 3) consists of:

* The thick PQ Group represented by dark coloured phyllitic shales whose base is unknown, with a continuous metric level of quartzites and associated limestone lenses at the top.

* The VS Complex conformably overlying with the PQ Group is an important acid volcanic pile composed of three different layers of pyroclastic tuffs which are separated by discontinuous shale formations. These tuffs are characterized as distal with lapilli to ash products, silicic to silicic-phyllitic in composition forming graded pyroclastic units. The presence over 3.5 km to the NW of the mine, of coarser agglomeratic tuffs and lavas indicates that the pyroclasts which precipitated in the basins were distal products of a felsic explosive

and eventualy subaereal volcanic event. The intercalated formations between each volcanic level vary from silicic-phyllitic red, gray-green to dark or black shales. The association of these shales with quartzites or clastic elements has a stratigraphic marker significance locally.

The Neves, Corvo, Graça and Zambujal ore deposits, are the four massive sulphide lenses known today, and they are located in this VS Complex. At the top of the uppermost acid volcanics, from which they are separated by discontinuous black shales.

* The Flysch Group overly gradationaly the existing ore deposits whose level is also markar by a thin jasper-carbonate-chloritic layer which has hydrotermal-sedimentary characteristics. This Flysch Group presents at Neves-Corvo a strong difference in relation with the IPB, namely the appearance of an intercalated volcanic-sedimentary sequence indicating a late reactivation of the volcanic activity, in the area (Carvalho, 1986). A low angle thrusting, which imbricates the structure of this sequence showing various tectonics units,' makes it difficult the read the true nature of all contacts, so that the entire lithostratigraphic column is not yet fully established.

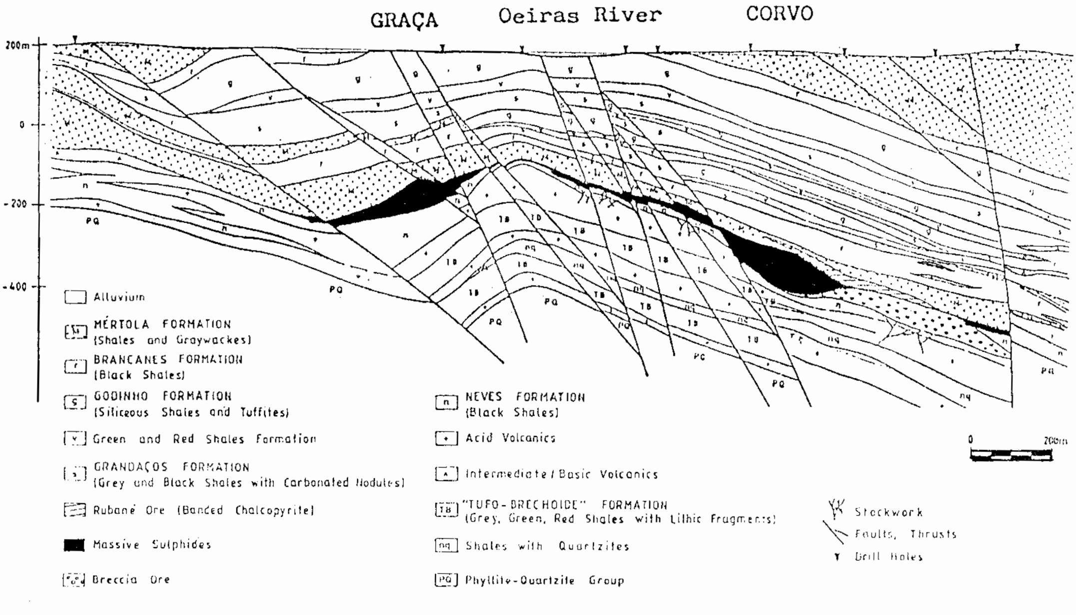

Figure 3. Geological cross-section.

Mineralogicaly various types of ore were defined in the deposits (figure 4), following the results of 130 km surface drilling plus 30 km of detailed underground drilling programs. The ore reserve estimates are being updated indicating a global cupriferous resource of 33.35 MT averaging 7.75% Cu, mainly on two Corvo and Graça ore deposits. There are 32.64 MT further resources of Pb, Zn, Ag complex ores at a 9% equivalent zinc content, and tin which is currently the subject of feasibility studies.

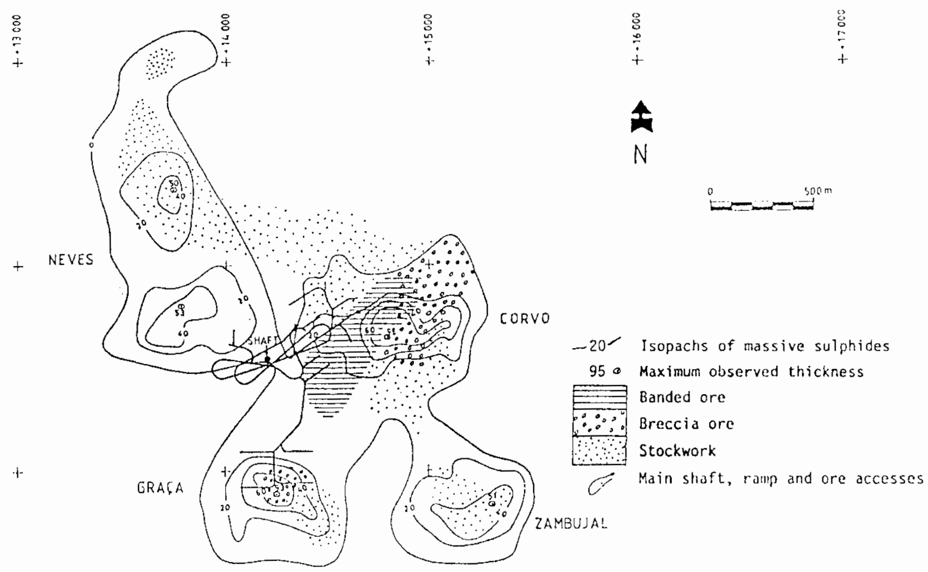

Figure 4. Distribution of the deposits and ore types.

Tectonically the area was active after the deposition of the volcanics, being affected by subsiding graben structures where diferent types of associations between ore, volcanics and sediments are seen. Development of thrusts, folding, faulting and regional schistosity follow the earliest stages of the Hercynian Orogeny. The youngest faulting occurring at Neves-Corvo are NS, NW and NE subvertical faults which cut all the lithological sequence displacing the structure and affecting the orebody morphology. The thrusts that affect the formations above the ore level are frequently associated with soft impervious layers of black shales which limit the hydrological systems defined at Neves-Corvo. The late subvertical faults with variable displacement and associated fracturing are the main collectors of water between those systems.

4. MINING-HYDROGEOLOGICAL SETTING

According to the investigation described later (Fernãndez-Rubio and Assoc. 1985, 1987) and from the hydrogeological point of view it is important to emphasize the following aspects:

* The Paleozoic-metamorphic rock formations described above, can be considered originally as a very low permeability complex.

* The macro and micro fissures produced during the polygenic and polychronic geological history of this area, provided a significant heterogeneous permeability, particularly into the compact and competent rocks and subvertical faults. In the future mining may also contribute to increased permeability.

* The whole can be outlined as a low permeability mass with some capability for water storage, affected by subvertical drains formed by

faults with low storage capacity but with high drainage capability.

* Globaly three main hydrological units are distinguishable:

  - Cutaneous Complex (CC). Aquifer or aquitard relatively heterogeneous, with permeability decreasing with the depth. Free or semiconfined. The CC Unit includes the alluvial terrace, and the weathering zone, and it is limited in depth to the uppermost thrust (figure 3).

  - Intermediate Complex (IC). Aquifugous assemblage crossed by vertical pervious faults, thus providing secondary heterogeneous permeability. Semiconfined or confined. The IC Unit is limited in depth by the Flysch Group just above the deposits.

  - Ore System (OS). Aquifers and aquifugous. Permeability is provided by microfissures in the orebodies. Confined. The OS Unit groups together the deposits plus the footwall formations.

Before mining works the only ground water flow was restricted to the CC Unit with small rain water infiltration and subsequently a slower discharge to the river and its small tributaries. The water pumping for irrigation and domestic consumption was very small.

5. MINE WATER INFLOW

The mining infrastructure for development of the project consists of a main ramp for labour and material access, approximately 5 km long from surface to the haulage level at the -300 elevation and a main 5 m diameter shaft for ore extraction whose final depth is 575 m. The rest of the developed infrastructures such as accesses to the Graça and Corvo deposits where exploitation will start, and other galleries and raises have modified the static or semi-static flow in the hydrological units, due to the water inflow to the underground mine works. This "call" for water from different depths has affected not only the water table but also the hydraulic balance of the aquifers.

During this construction, the inflow of water appeared associated with subvertical faults and with the vicinity of sub-horizontal thrust. This inflow was controlled by grouting injection, despite its increase with the depth and mainly in the ore crosscuts up to $260 m^3/h$ on a single face. As the mine was deepened, new intersections of the same structure resulted in the water from higher levels reporting to the deepest galleries cutting the thrusts. The same behaviour was observed in the ore body crosscuts, with previous inflows drying up in favour of new deeper intersections.

The main effects were as follows:

* The original Oeiras gaining stream, is now a losing river in the area affected by the cone of depression.

* With the water table drop a substantial reduction in evapo-transpiration rate was produced.

* Mine water inflow came from: a) fossil salty water stored in the OS Unit, b) water stored in subvertical discontinuities and into the pervious materials of the IC Unit, c) water stored into the CC Unit, and d) rain and surface run-off infiltrated water mainly from the Oeiras River. Waters related to group c) and d) are the most significant.

A conceptual model can be built based on these effects, with the CC Unit being the main collector of infiltrated rain and run-off water; the IC Unit is a transfer unit through subvertical faults, provoking the discharge of the water into the mine works that cross those faults and acting as an important feeder of the OS Unit that is being drained.

This conceptual hydrological model has been developed according to the data collected during the mining-hydrological studies.

6. HYDROLOGICAL INVESTIGATIONS

We now summarize the research program undertaken in the meantime in order to fix the origin of such water inflow and to reduce the unfavourable water effects.

6.1. Thermometric control

The water temperature can be used as a tracer of the ground water flow and its origin. The water temperature recorded during our studies in 1985, along the ramp and shaft, provided an increase of 1 ºC each 30.3 m of depth with a correlation coeficient of r=0.97 (figure 5). Such conduct reflected a normal uniform geothermal gradient that is to say the ground water had enough time of residence to acquire the temperature according to the depth. Similar thermic gradient was determined by the borehole logs (figure 5).

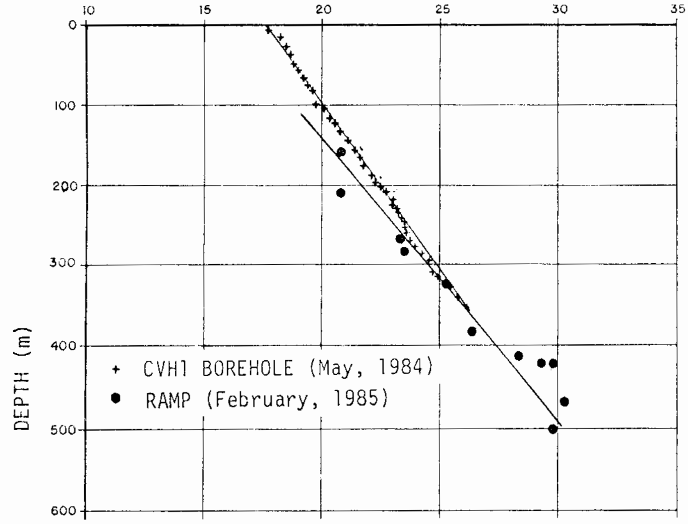

Figure 5. Ramp inflow water temperature and CVH1 borehole log temperature.

However in the same and subsequent controls we found a lower temperature than the expected in water inflows related to the main subvertical faults, reflecting a quick descendent drainage through these preferred channels.

The isothermic vertical cross section is shown in figure 6.

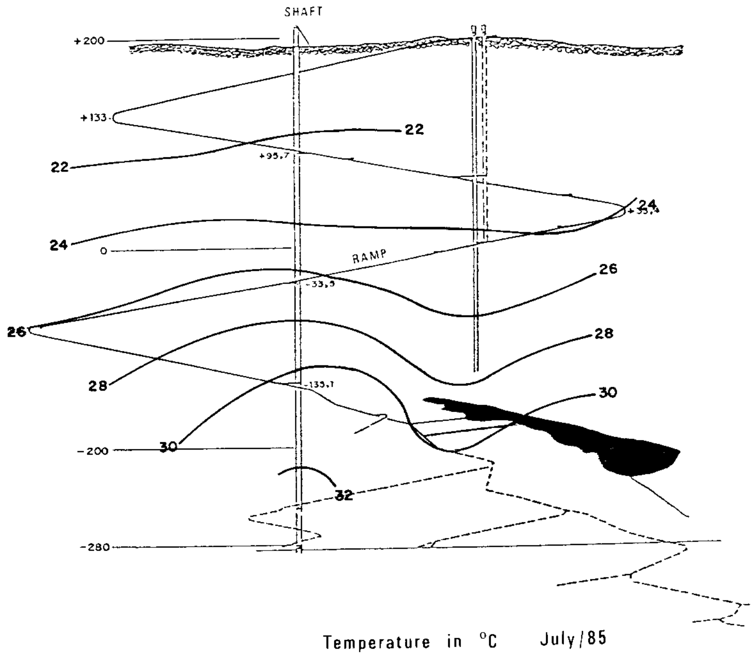

Figure 6. Water temperature cross section.

6.2. Hydrochemistry control

Since the beginning of our studies, hydrochemistry of superficial and ground waters has been periodically controled with the determination of: Cl^-, $SO_4^=$, HCO_3^-, $CO_3^=$, NO_3^-, NO_2^-, Mg^{2+}, Ca^{2+}, Na^+, K^+, NH_4^+, Li^+, B, P_2O_5 and SiO_2, together with conductivity, total disolved solids, pH, CO_2 , and others physico-chemical parameters.

Hundreds of analysis which have been carried-out, giving very valuable information about the hydrogeological behaviour of the systems. It is not possible to describe here all the hydrochemical investigations carried out, so we will pay attention only to some representatives ones.

There is a very clear relationship between the increase of the total dissolved solid (TDS) and conductivity with depth (figure 7). As we have said before, the fossil salty water is being progressively replaced by recent infiltrated water with low salinity. In the same sense there is a gradual change of chemistry from calcium or magnesium bicarbonate water in the CC Unit to sodium chloride water in the OS Unit.

The vertical sections showing contours of ion contents, following the axis of the ramp, demostrate a conical morphology with concavity looking upward (figure 8), which is a very clear indication of descendent water flow

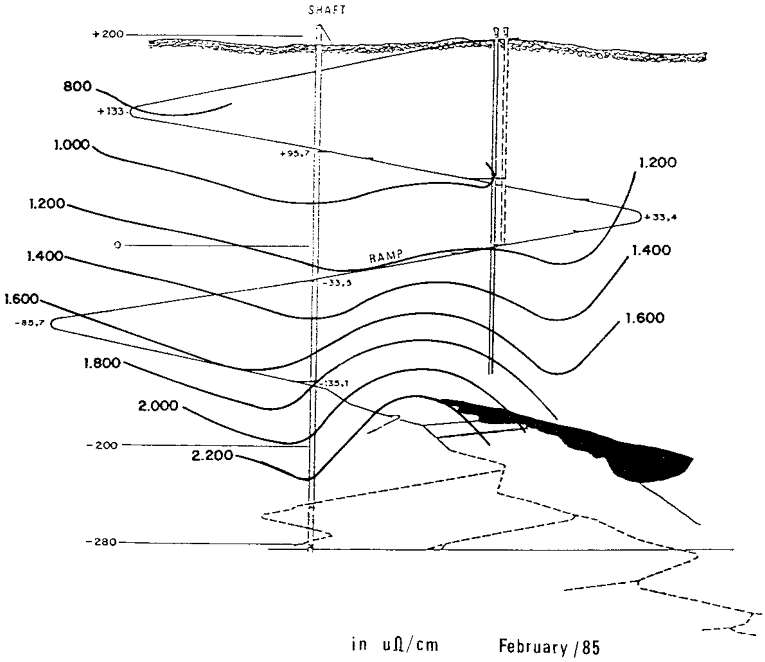

Figure 7. Water conductivity (in microsiemens) through a ramp vertica cross-section.

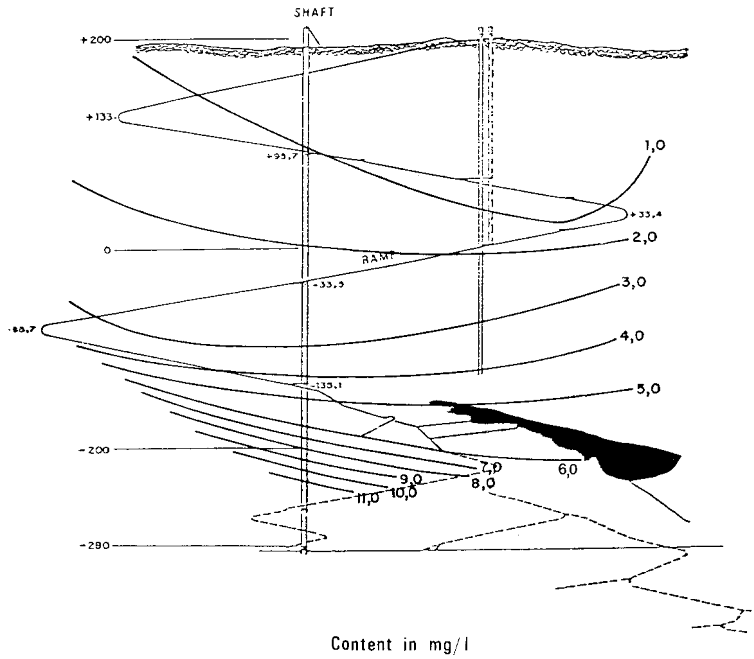

Figure 8. Water potassium content through a ramp vertical cross-section.

provoked by the drainage through the orebodies and shaft. Such variation i clearly seen in all the evaporite ions, related with the submarin sedimentation:

Ion	Water contents rate (increment every 100 m)	Correlation coeficient (r)
Chloride	150 mg/l	0.90
Sodium	141 mg/l	0.88
Potassium	130 mg/l	0.91
Lithium	0,1 mg/l	0,91

6.3. Piezometric control

Before the excavation of the underground infrastructure the water table was very close to the topographic surface. The water flow was subhorizontal and mainly imposed by the Oeiras River drainage during the dry season.

During the mining excavation of the underground works a large irregular cone of depression has been developed. This drainage effect is more significant in the OS Unit, and mainly following some very important faults crossing the Oeiras River meander (figure 9).

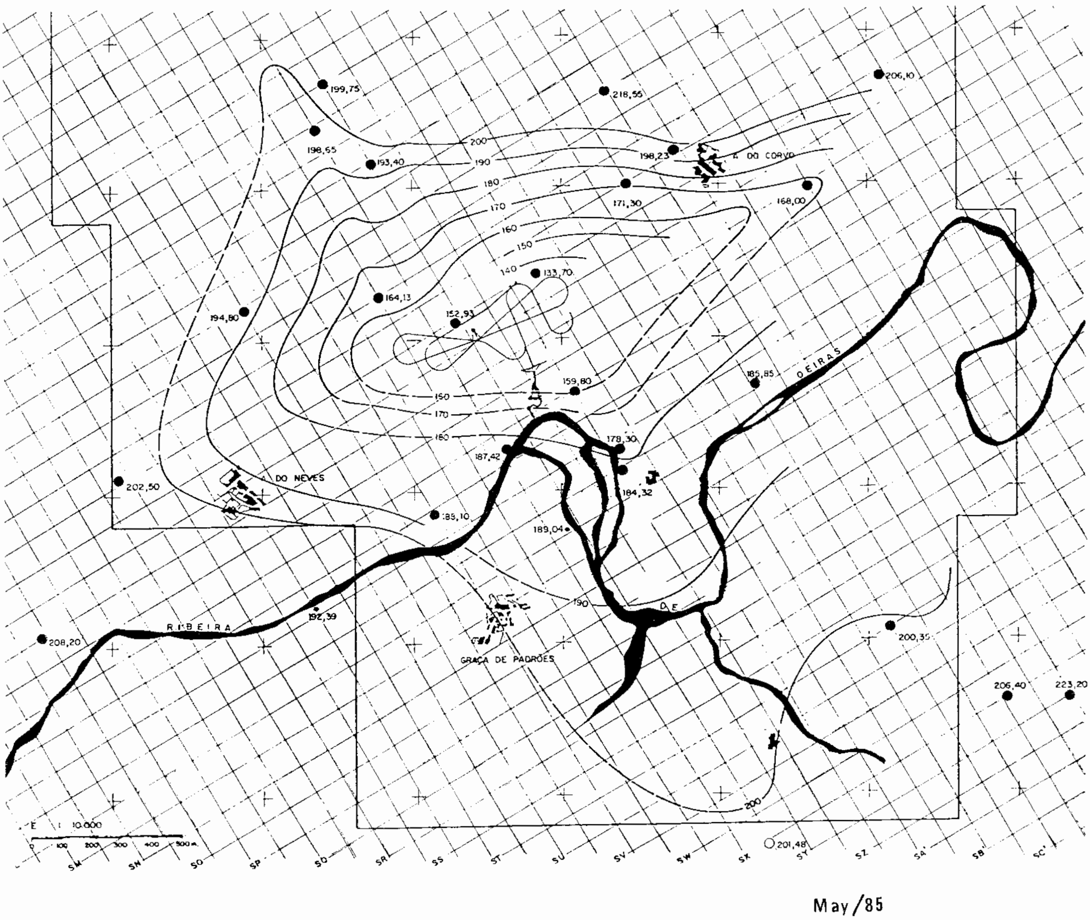

Figure 9. Cone of depression provoked by the mine drainage.

Ussualy there is no influence of the mine drainage in the piezometers around the mine at a distance greater than 2 km. The small water table fluctuations show seasonal changes: slow drop during four to eight months with rapid recovery during one to three months. The piezometers located between 1 km to 2 km from the mine usually reflect a smooth lowering, with partial water level recovery after the rainy period. The piezometers near the mining works show a similar behaviour to the preceding group followed by a rapid drop. Most of the piezometers near to Oeiras River show the effect of lowering level provoked by the mine drainage superimposed on total or partial water level recovery during the run-off periods.

Due to the river feeding to the mine workings through subvertical faults, the extension of the river dry watercourse is growing year by year and the period of the drying-up of the river is longer.

The piezometric records clarified the following aspects:

* the increasing of the area affected by the mine drainage,

* the heterogeneity of the hydrogeological behaviour with preferred draining channels, and

* the recharge effect provoked by the rain and run-off infiltration and the very good connection between the deep OS Unit and the upper hydrological CC Unit.

6.4. Isotopic dating

In order to determine the duration of water residence we have studied the Tritium contents of some water inflow. This radiactive isotope allows the "age" of the water infiltrated after 1952 (turnover time) to be established. With such dating we can distinguish three types of water (figure 10):

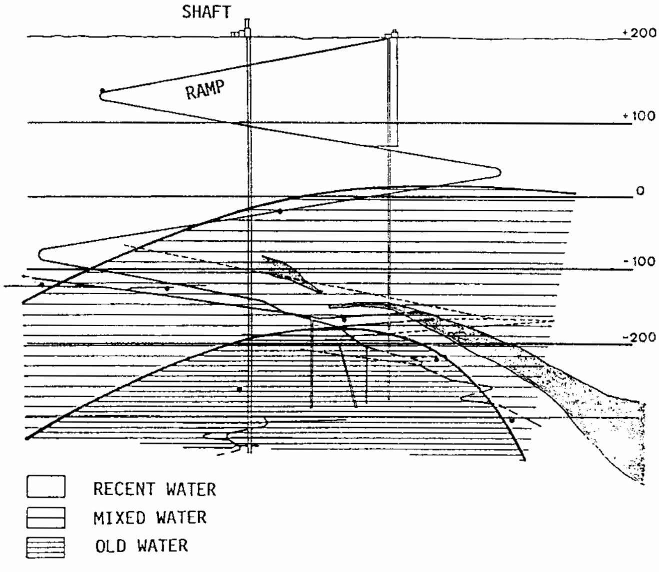

Figure 10. Water age zonation through a ramp vertical cross-section.

* Recent water with very similar age when compared to the rain and run-off water. At the begining such water appears only in the upper zone (CC Unit), later we find it in lower units.

* Mixed waters (average 40% recent and 60% ancient) located in the middle zone or in deep very pervious faults or orebodies, corresponding to the IC Unit and the Uppermost OS Unit.

* Ancient water (rainfall before 1952) flowing in the deepest works associated with the OS Unit.

This data confirms the age stratification of the ground water in the different superimposed hydrological units.

The periodical application of this method proved the gradual sustitution of old by recent water that flows in the mine works.

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