CONSEQUENCES OF PUMPING CESSATION AT REOCIN MINE, CANTABRIA (SPAIN)

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Abstract
In order to evaluate the mine flooding effects as consequence of pumping cessation by mine closure, hydrogeological studies have been accomplished on the area of Reocín mine. A hydrogeological subsystem of the Santillana synclinal aquifer system has been defined. It consists of carbonate materials of Gargasian to Cenomanian age, with confining levels belonging to Cenomanian and Bedulian. For an elevation of -500 m below sea level, water reserves of the Reocín hydrogeological subsystem are 36.5 Hm^3 in mine voids and between 94 and 184 Hm^3 in the Gargasian-Albian aquifer. Piezometric simulations have been made for current pumping at elevations of +13 and +60 m (natural overflow) above sea level. These simulations have allowed to predict the evolution of the piezometric levels and to determine the responses of water flow to different heights of water level in the open pit. Mine operations have improved the hydraulic characteristics of the hydrogeological subsystem. It could be possible the use of the underground reservoir for Saja and Besaya Rivers regulation and for reinforcement of the urban water supply in dry seasons.

Introduction
Reocín mine is located 3 km south-western Torrelavega village, in Cantabria (northern Spain). The mined area is part of the eastern flank of Santillana synclinal that is a great hydrogeological system in Gargasian – Lower Cenomanian materials (Fig. 1). During the mine operations, the water influx to the mine (up to 1,299 L/sec) was a major problem for exploitation works. On the Santillana synclinal aquifer system, the Reocín hydrogeological subsystem has been defined. The limits of this hydrogeological subsystem are: the Saja River, constant water level against any extraction or infiltration in the subsystem, that constitutes a limit of influence to north and west; the Bedoulian marly limestones that constitute a stratigraphic limit to east and south. The low permeability of these limestones has been evidenced in the course of the mine life (Alonso, 2006). On the contact surface there is an important sin-sedimentary karstification that constitutes a preferential water circulation level with collapsed dolines where the permeability is high. At the minesite, the aquifer sequences are affected by a strong dolomitization with loss of permeability to the borders of areas with facies change. The confining levels of the Reocín aquifer are constituted by marl limestones (Beduliense) on the base and by an alternation of sands and clays levels (Lower Cenomanian) with low vertical and horizontal permeability.

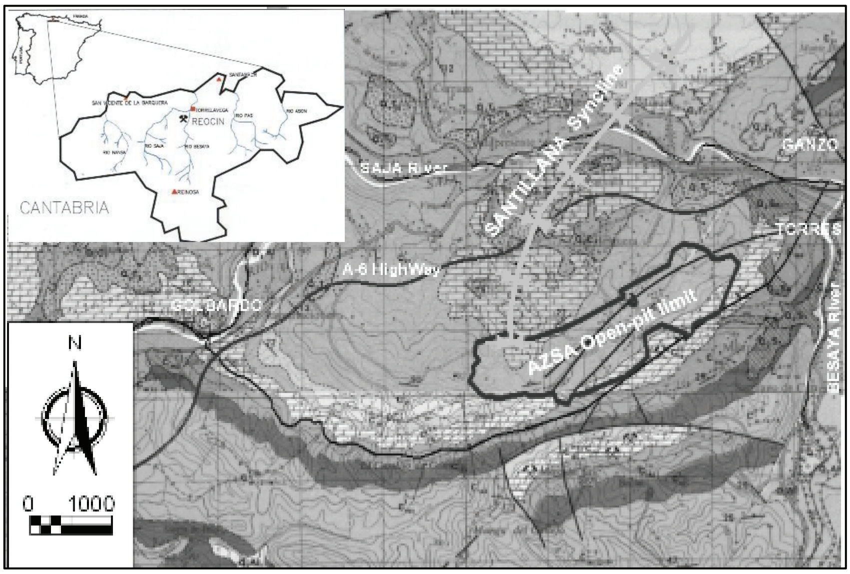

Figure 1. Geological map and location of the study area.

The influence of the mine drainage on the Saja River was a serious problem during the mine exploitation, especially from the 1980s when the ore was exploited at the 21st level in the west zone. The existence of collapsed doline levels favoured the water communication (Fdez et al., 1992). The Saja River water flow measures made in 1993 by IGME (Geological and Mining Institute of Spain) in five sectors of Golbardo Area gave water losses of 450 L/sec on the contact between Upper Albian and Cenomanian.
The lithology of the Reocín hydrogeological subsystem is made up of intensively fractured calcareous dolomitic rocks which constitute the aquifer. This hydrogeological subsystem can be assimilated to a porous medium where the hydrogeological classical formula can be applied. The stratigraphic sequence of the Reocín hydrogeological subsystem is well known (Fig. 2), and four regressive sequences of a great hydrogeological importance have been determined. These sequences condition the karstification and consenquently a preferential water circulation in the aquifer system (Fernandez Rubio, 1980, 2004).
The Reocín aquifer reservoir is constituted by two sequences formed by two carbonatic levels. The tidal and supratidal levels located over these sequences are responsible for a karstification with spectacular collapsed dolines. The carbonatic levels are intensively fractured with a dense network of fractures finishing on the sand interfacies. They give rise to anisotropic and heterogeneous levels with zones of preferential water flow corresponding to triple porosity aquifers: karstic channels, fractures and matrix porosity. As a whole the porosity is comprised between 1 and 2 % (Llamas, 1976).

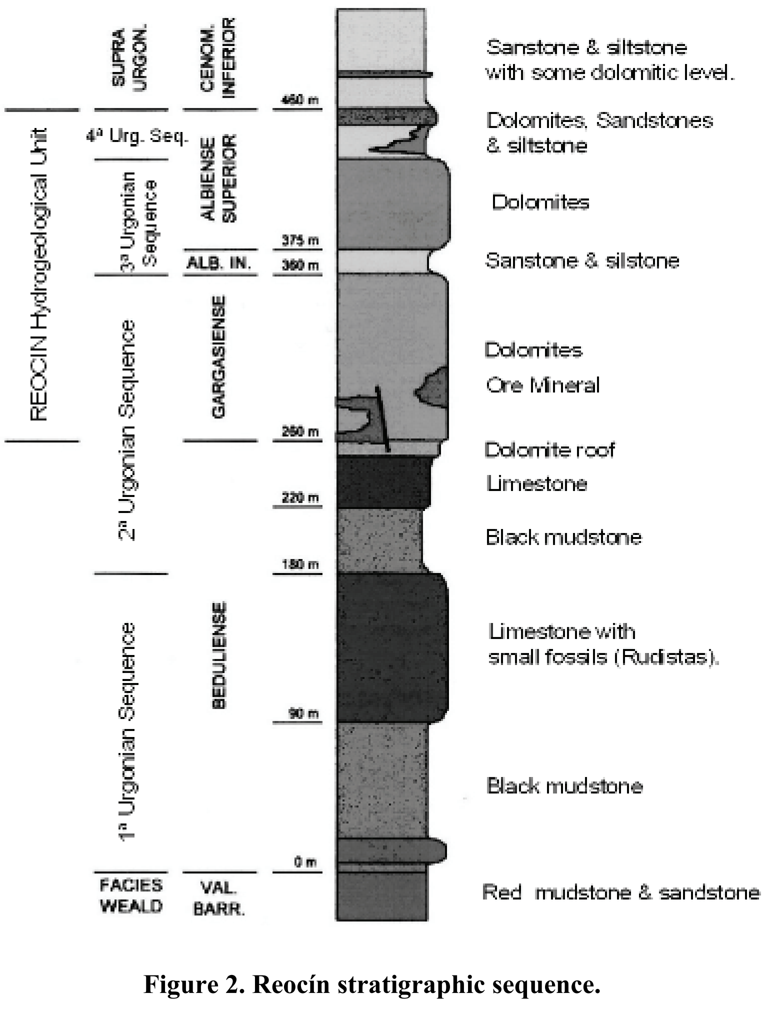

Figure 2. Reocín stratigraphic sequence.

Methods

The use of the classical hydrogeological methods of study in fractured and karstic aquifers is based on the treatment of the aquifer levels as a continuous media. This is under the consideration of a rock volume at a macroscopical scale assumed to be equivalent to an ideal granular porous media. In these conditions the main parameter governing the water flow is the hydraulic conductivity, which must be applied on a minimal elemental volume bigger than the microscopic pores, in order to predict the water flow according to the Darcy law. The

stratigraphic sequence has been recognised on the field and also data corresponding to more than 900 wells and piezometers have been treated in office. With the litostratigraphic data from drills, TVT (True Vertical Thickness) isopach maps have been produced. Geological sections of the area allow to visualize in depth the geological structure.
Finally a three-dimensional modelling of materials forming the chronostratigraphic series of the Reocín hydrogeological subsystem has been made. Permeability has been calculated by analytical estimations and by Jacob method.

Results and Discussion

The pumping suspension at the mine began the 1st November 2004 and the 20th March 2006 the water level of the open pit had reached an elevation of +13 m above sea level, where it is currently maintained by pumping of 330 L/sec. In Golbardo area, the water level, controlled by piezometer measurements, has raised in the order of 5 meters; in periods of high waters there are sporadic seasonal increases forming mounds by the recharge of the river water. They afterwards disperse to decrease at the level of the aquifer natural discharge, corresponding with the contact Albian – Cenomanian at an elevation between +50 and +60 m above sea level, increased with the corresponding gradient.
The old drainage gallery turned later into a drainage gallery for mine water pumping at an elevation of +34 above sea level up to the beginning of the 1980s. The old outlet at an elevation of +32.8 m above sea level is blocked by a waste landfill from the freeway. There is a circulation of ascendant water through the abandoned mine works producing an increase in ions content in the water flow direction. With cessation of pumping water in the open pit, the water level could rise up to the overflow at the elevation +60 m above sea level. Water flows are not possible to predict in a reliable way by the effects that mine works provoke on mine water drainage (Trigueros, 1986).

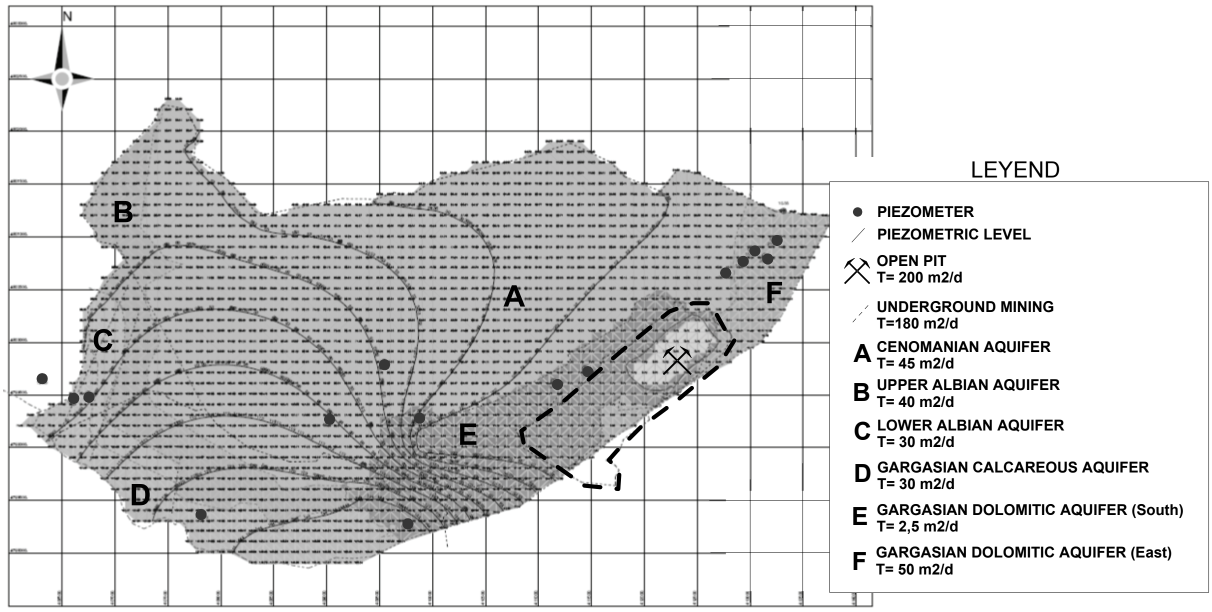

Figure 3. Model in permanent regime of piezometric levels for an elevation of +13 m above sea level.

From permeability, recharge, aquifer thickness, and other hydrogeological data, flow models in permanent and transitory regimes can be established in order to reflect the different hypothesis and responses of the hydrogeological subsystems for different pumping options. Figures 3 and 4 reproduce the model in permanent regime of the piezometric levels with the current water pumping of 330 L/sec at an elevation of +13 m above sea level. This figure reproduces the water flow towards the Saja – Besaya Quaternary formations with water level for an elevation of +60 m above sea level (natural overflow).
The underground water flow between the open pit and Saja River in Ganzo area has been calculated by simulations. Water flow is moderated (between 6 and 15 L/sec) and it will be absorbed by the aquifer with Quaternary materials between Saja River and the Reocín hydrogeological subsystem. Underground water flow between the aquifer and the Saja River in Ganzo area has been calculated for different simulations and it is indicated in Table 1.

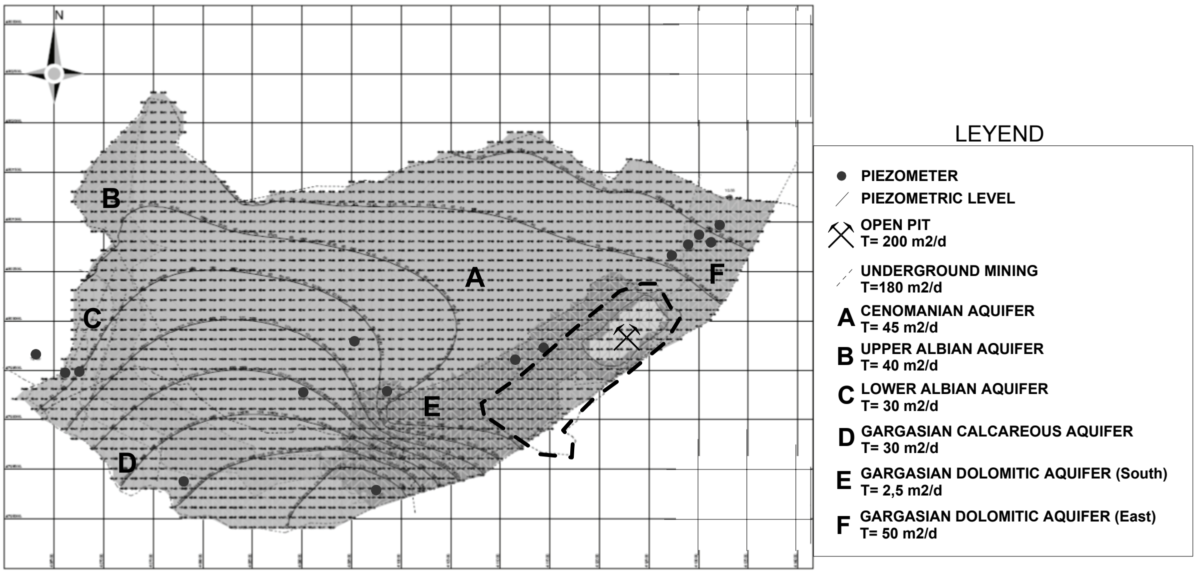

Figure 4. Model in permanent regime of piezometric levels for an elevation of +60 m above sea level.

Table1. Estimation of groundwater flow between aquifer and the Saja River in Ganzo area.

Simulation	Water flow (L/sec)	Direction
Underground exploitation	45	Incoming to aquifer from river
Flooding at +13 m	6	Outgoing from aquifer to river
Flooding at +20 m	7	Outgoing from aquifer to river
Flooding at +40 m	9	Outgoing from aquifer to river
Flooding at +60 m	10	Outgoing from aquifer to river
Natural regime	15	Outgoing from aquifer to river

In Reocín mine there is an underground reservoir with capacity of 9.7 Hm^3, corresponding to the underground mine works, and an open pit reservoir of 26.8 Hm^3, up to the elevation of +60 m above sea level. Water reserves of the Reocín subsystem are estimated between 92 and 184 Hm^3, with a great capacity to be used as regulator of the Saja River and even in the Besaya River. During the mine exploitation this underground reservoir has behaved as a regulator for the Saja River, acting the mine water pumping as floodgate of the reservoir. After mine closure, the floodgate could be a nest of pumping drills to place in any area of the aquifer; the most suitable area can be the old mine works, where practically it would be to pump from an underground reservoir “sensu stricto”. Another option could be wells placed near the riverbed, used as ASR (Aquifer Storage and Recovery) wells which serve for the recharge and recuperation of water from the system. In a hypothetical case without pumping the water to drain is the infiltrated in the spoil heap and in the open pit.
At the current situation, with water level stabilized at an elevation of +13 m above sea level, the geochemical analyses of water in the Saja River, upstream and downstream the Reocín aquifer, do not show water contributions from the aquifer to the Saja river (Seebold et al., 1992). Experiments of mine water neutralization have been made by interaction of water with know chemical composition with fragments of dolomite with a settled size. The water flow through the fragmented dolomite makes pH reach alkaline values in a brief period of time causing the iron and manganese precipitation and a great part of zinc too.

Conclusions

In the Reocín hydrogeological subsystem, materials of Cenomanian and Bedoulian age are confinement levels of the Gargasian-Albian aquifer. The dolomitic calcareous rocks constituting the aquifer are intensively fractured and can be assimilated to a porous medium where the hydrogeological classical expressions can be applied. Permeabilities are comprised between 0.3 and 0.5 meters by day in Torres area and between 1 and 4.5 meters by day in Golbardo area. They are conditioned by collapsed paleo-dolines, which originate preferential circulation paths. Permeability is lower to the east and west than to the north of the mine, and this is as consequence of the intensive dolomitization. Data from drills and isopach maps reveal a blocky structure making evident the existence of fractures.

The cessation of the current pumping would originate an increase of the piezometric level which will improve the water quality and the decrease of the water flow through the mine voids (Fig. 5). Water reserves of the Reocín hydrogeological subsystem are 36.5 Hm^3 in mine voids and between 94 and 184 Hm^3 in the Gargasian-Albian subsystem of Reocín.

A water flow model in permanent regime has been elaborated. It has been checked and contrasted for two differents times: during the mine exploitation and for the current pumping level of 330 L/s at +13 m above sea level. This model allows to predict the evolution of the piezometric levels and to determine the responses of water flow to different heights of water level in the open pit (+40 and +60 m above sea level). According to simulations of underground water flow in the model with mine under exploitation and pumping station at -272 m below sea level (reference system), the water flow direction came mainly from north and east, corresponding to Saja River infiltrations. Simulations of mine flooding at different elevations show a complete change in origin and direction of underground water flow. At current situation of open pit flooding at +13 m above sea level (reference system), the water flow came from the endoreic basin of Burco, which supply as well the water pumped from the open pit to Saja River. The simulation of mine flooding at +60 m reinforces the idea that the endoreic basin of Burco creates a mound that is the origin of the underground water flow. This underground water flow is mostly addressed to north and west, reaching the Saja River, and to a lesser extent towards the east reaching the open pit. Finally in the simulation corresponding to the natural regime, considering the absence of mining works and, consequently, without water pumping from the open pit, the underground water flow from the karstic endoreic basin of Burco shares in west, north and east directions. The most important flows correspond to west and north.

The Reocín aquifer subsystem could be used as an underground reservoir. The mining exploitation has improved the hydraulic characteristics and it could be possible the use of this underground reservoir for Saja and Besaya Rivers regulation by means of ASR (Aquifer Storage and Recovery) wells and for reinforcement of urban water supply in dry seasons in the area.

Figure 5. Two different phases in the open pit filling (Right, elevation 0 meters; Left, elevation +13 meters above sea level).

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