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title: **Hydrogeological studies in diapiric-layering salt formations: The case of the East of Catalonia Potassic Basin**

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INTRODUCCION AND GEOGRAPHICAL SETTING

The Catalan Potassic Basin (CPC), located 70 km NW from the City of Barcelona (Fig. 1), is usually described as a part of a regional tick regressive-sedimentary EbroTertiary Basin that includes marine, evaporitic-transitional and continental facies, overlying by no-consolidated quaternary alluvial sediments and affected by Alpine-related tectonics structures (faults and folding). The main rivers in the CPC are the Llobregat and Cardener. The current hydrogeological knowledge of the area is poor and it is basically restricted to the shallower formations (less than 50 meters depth).

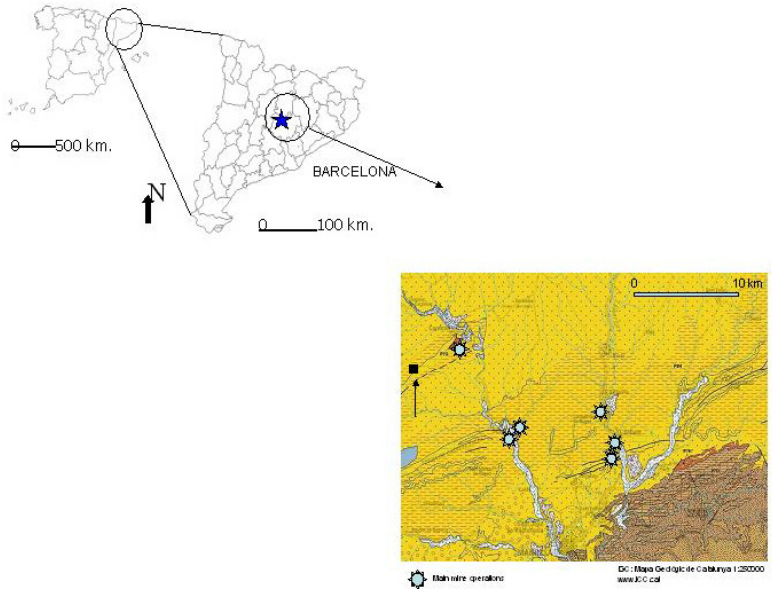

Figure 1. Geographical and Geological map of the Study Area showing the main mine works after ICC, 19XX. Geological map legend: Grey: alluvial unconsolidated Quaternary formations. Yellow: upper Paleogen Formation (Eocene-Oligocene). Brown: lower Paleogen Fm.

The natural salinity of the quaternary alluvial aquifer is low and it is mainly related to the salinity of the river and the lateral groundwater inflow from the Tertiary aquifers. In the Tertiary aquifers salinity seems to increase with depth. The piezometric relation between these two aquifers also controls the hydrogeological and chemical behavior in the Basin. Both aquifers, specially the alluvial one, are used for urban supply or local irrigation, and the Llobregat River is the main recharge source for the Lower Valley and Delta aquifers, located 60km SE, that are an strategic reserve of fresh water for Barcelona Urban Area.

The intense underground mining activity used in the exploitation of K-salts (Silvite and Carnalite) in the CPC during the last century, has provoked the appearance of saline springs and/or the salinization of old ones (Fig. 2a), groundwater contamination mainly from dumps (Fig 2b) and probably, the existence of subsidence and dissolution sink holes areas (Fig. 2c).

HYDROGEOLOGICAL CONTEXT

The objective of the actual hydrogeological studies in the CPC area is focused on the characterization of the Tertiary and alluvial aquifer in order to define their conceptual model. To obtain

this information several investigation wells and piezometers with different depths were drilled and geophysical testified in both aquifers to obtain information of: groundwater levels, hydraulic parameters, hydrogeochemical compositions, thermal gradients and isotopic signatures.

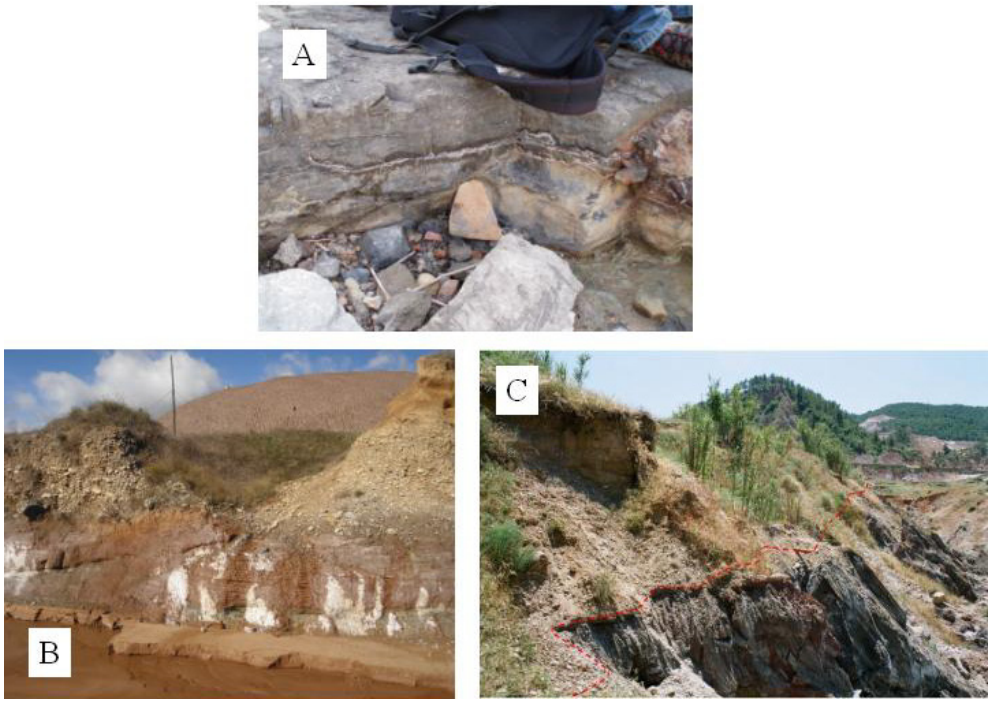

Figure 2. A) High salinity groundwater flowing across the Carbonate Tertiary fracture system and related white halite crystallizations (Sallent). B) Salt dumps, composed mainly by halite, with minor concentrations of K-chloride minerals, and mud flotation tails with organic compounds (VOC's and SVOC's). C) The existence of underground potash mining provoked, in some areas, subsidence and collapse problems were groundwater plays a critical role, e.g. part of the Cardener alluvial meander in the locality of Cardona, collapsed in 2002 due to a salt cavern generated in its base.

Regional piezometric context of the Tertiary formations described a general N-S, NW-SE flow in the area (Fig. 3), but several local singularities must be considered:

- The existence of preferential flow across the main fracture zones that locally modify the general distribution of the hydraulic gradient. In some of these areas (e.g. Llobregat River, in Sallent) the piezometric level could be periodically higher than the river bed surface level.
- Permanent main rivers (Llobregat and Cardener) and their second or third order ephemeral tributaries are the principal drain systems of the alluvial and Tertiary aquifers.

The distribution of the hydraulic parameters showed lower transmissivity in Tertiary formations (T from 0.1 from 15 m^2/d) and higher ones in alluvial sediments (T from 1 to 400 m^2/d). Otherwise, the trasmissivity in fractured Tertiary areas could reach 1 or 2 orders of magnitude higher than the regional average.

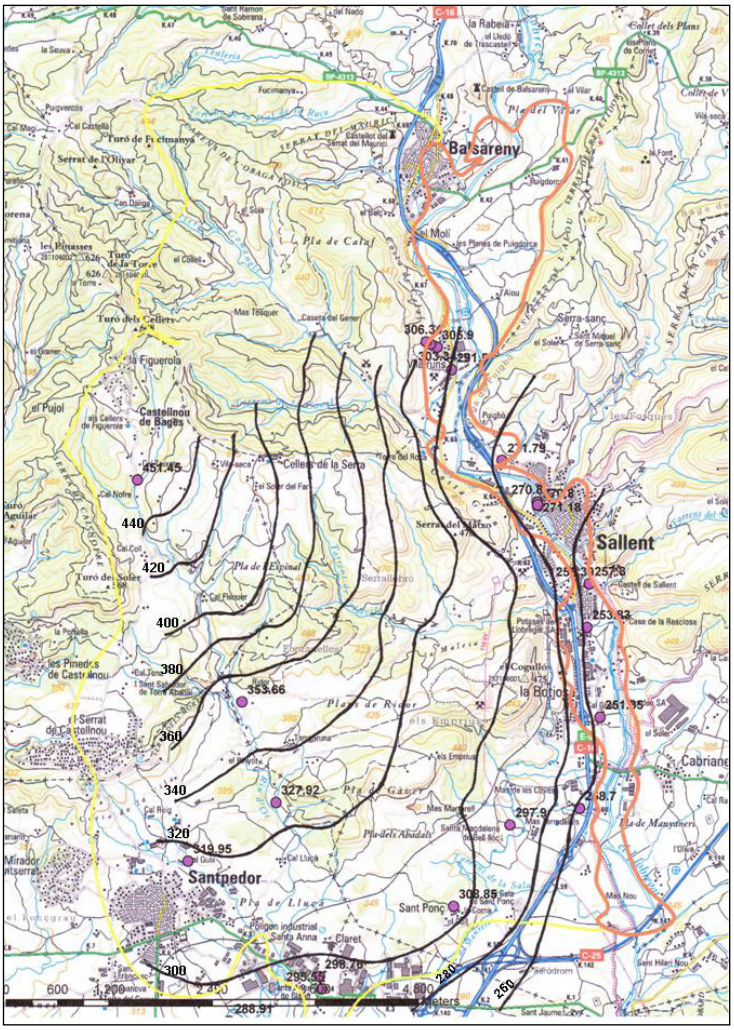

Figure 3. Piezometric regional map of the Tertiary formations in Llobregat-CPC area (composed partially with data from Escorcia, et al., 2009).

The hydrogeochemical and isotopic studies revealed a regional fresh water input in the shallow Tertiary and alluvial aquifers, and their coexistence with two main salinization sources:

- A saline natural source related to the Eocene marine salt layers that showed an increase in salinity with depth across the Tertiary formation,
- Anthropogenic saline point sources related mainly with K-mine dumps, and the rest of mine installations (usually associated with VOC's and SVOC's compounds). In that context, the influence of the saline plumes is basically found in the shallower levels of the aquifers.

The ratio between K and Cl is useful to fix other hydrogeological controls. The K-Chloride minerals (Carnalite and Silvite) solubility is higher than Halite solubility (Fig. 4) and also they are minor components of dumps.

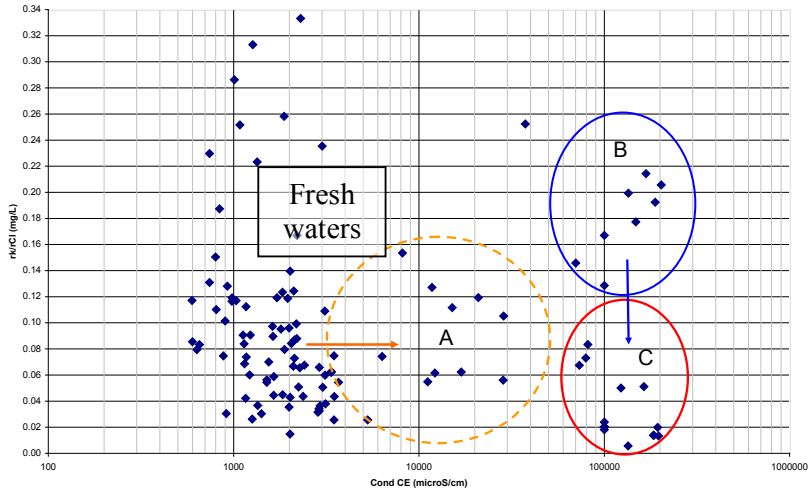

Figure 4. rK/rCl .vs. EC. Group A: fresh regional waters partially affected by salinization. Group B: saline groundwater not affected by selective removal of K (water recharged from actual dumps or Tertiary regional deep water circulating along K-rich formations), Group C: saline groundwater affected by selective removal of K-rich minerals (water recharged from old dumps or preferential flux along regional faults).

This difference produces two main effects in the area:

- The existence of a rK/rCl specific signature related to the age of the dumps, where old dumps have lower rK/rCl than the new ones,
- The probable difference in these indexes between the regional deep flow, and a more localized preferential flow, with higher rK/rCl, governed by regional Alpine faults systems, from the deep Tertiary aquifer towards the surface.

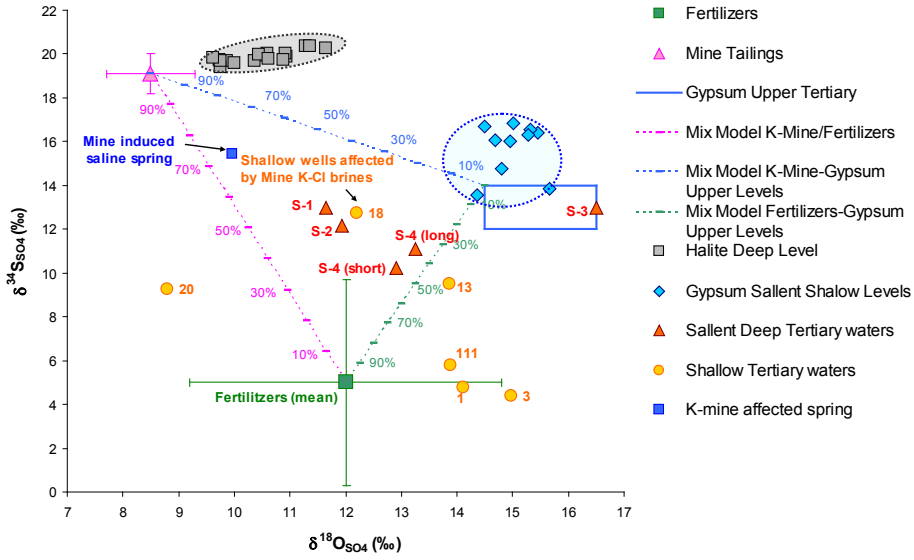

Figure 5. $\delta^{34}S$–$\delta^{18}O$ plot indicating the salinity origin, according to Otero and Soler 2002, 2003.

Dissolved sulfate isotopic composition has been demonstrated as a tool to distinguish the origin of salinity in the CPC (Otero, Soler, 2002; 2003). Sulphate isotope composition of shallow Tertiary waters indicates that salinity is the result of a mixing within natural sulphate and sulphate form fertilizers; only in the case of two wells (indicated in figure 5) it is clear the influence of mining activity. In the case of deep Tertiary wells, well S-3 shows that salinization is from natural interaction mixed with sulfate from fertilizers used in the area. In deep wells 1 and 2, salinity is the result of a fluid mix from natural interaction with the upper levels of Tertiary materials, sulfate from fertilizers and Halite-Potassic levels. In these wells is not possible to distinguish between natural interaction with sedimentary rich-potassium levels and mining lixiviates who show the same isotopic signature.

CONCEPTUAL MODEL

Recharge from rain infiltration is the main input of water in CPC Tertiary aquifers, that is complemented by lateral groundwater inputs, basically from their north limit. The general behavior of this aquifer is a typical multilayered one. The porosity seems basically secondary, where the water flows by strata discontinuities or major order faults. The Tertiary aquifer regional hydraulic parameters are low, with T around 0.01 to 1 m^2/d. Otherwise, the existence of Alpine faults provoke a local increment of hydraulic conductivity in these formations, that in some assays could be two orders of magnitude higher than regional values. In these faults areas, an augment of the vertical thermal gradient of water in wells, compared with the regional ones is also detected.

Rivers are the main natural drainage system of the Tertiary aquifer. The most part of groundwater are fresh, with no important Cl- or Na^+ concentrations and moderate quantities of SO_4^{2-}, but point and diffuse saline springs exist, related to contamination from mine dumps and/or natural piezometric regime. In these second group, the main occurrences seem to appear in the Llobregat River in Sallent, and in the upper part of Conangles River (2 km North from Sallent city) related in both situations with faults. Hydrogeochemically, the Tertiary aquifer shows a vertical distribution of salinity, with deeper levels showing increasing Cl, Na or K concentration and decreasing NO_3, compared with shallower ones. This vertical distribution is locally modified by the contamination provoked by the mining installations, with high salinity plumes moving across the upper Tertiary formations and, if the geological and piezometric conditions are favorable, using the same preferential pathways than the regional flow, producing in some cases the salinization of historic fresh springs.

The combination of faults or other type of discontinuities, and the existence of preferential flow in these zones, have probably induced or accelerated problems of instability and surface collapsing of some old Potash Mines in the CPC. In some cases, engineering solutions have been proposed. In others, preventive actions have been taken.

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