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## Extended Abstracts

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title: **Hydrogeochemical zoning in the delta of the River Andarax (Almería, SE Spain)**

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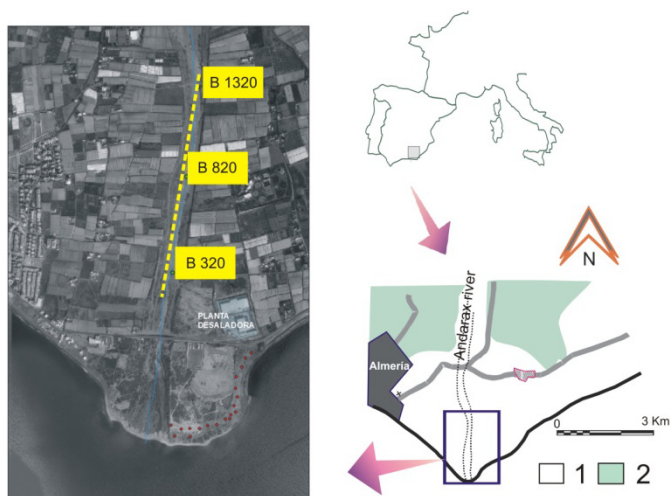
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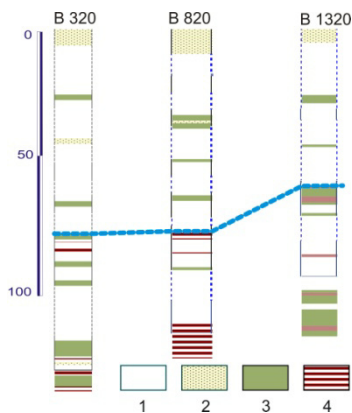
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## INTRODUCTION

The delta of the River Andarax occupies the coastal section of a detritic aquifer that extends along the central sector of the valley. It comprises Quaternary alluvial and deltaic deposits, together with Pliocene fluviodeltaic sandy and silty conglomerates. This is a free aquifer but the presence of lutitic beds in the delta gives rise to local, confined sectors. The piezometric surface show wide variations as a function of rainfall and surface water flow in the River Andarax (Sánchez-Martos, 1997). A desalination plant is located near the coast, taking seawater from a number of coastal boreholes (Fig. 1, 2).



**Figure 1.** Situation of the river Andarax delta indicating the observation boreholes (B-320, B-520 and B-1320) situated in the river bed. The white dotted line indicates the position of the cross-sections represented in Figure 2. 1 — Quaternary deposits (gravels, sands and silts); 2 — Pliocene deposits (marls and sandy silts).



**Figure 2.** Transverse geological section as indicated in Figure 1 by the white dotted line. 1 — Heterometric sands and gravels; 2 — Gravels, sands and clays; 3 — Fine sands and silts; 4 — Lutites.

The geological series comprising the delta aquifer has been described on the basis of three borehole logs, drilled to a depth of 110–130 m. These deposits are basically coarse detritic depos-

its: gravels with sandy intercalations and small cemented beds that are continuous over the three boreholes logged, and which serve as a reference for separating the aquifer units. The upper unit is quite homogeneous, consisting of sands and medium-coarse gravels. The underlying unit has a more heterogeneous lithology, mostly medium and coarse gravels but with more abundant sand and silt layers than in the upper aquifer, which are locally cemented. Between 100 and 120 m depth appear some very fine sands, marly silts with remains of bioclasts, with local occurrences of highly plastic blue silts containing some clay (Sánchez Martos et al., 2007; Jorreto et al., 2009).

The aim of this study is to demonstrate the difficulties that arise when studying the hydrogeochemistry of highly complex and variable coastal detritic aquifers, where there are frequent changes of facies in both the vertical and horizontal planes. These difficulties are compounded by the presence of saline deposits and levels of varying permeability, all of which contribute to the presence of different water types with varying salinity and highly contrasting geochemical evolutions.

## DATA

Data were collected from different depths in three boreholes in the bed of the river Andarax (Figure 1), over two surveys in April 2006 and June 2009. Sampling was preceded in each borehole by a series of tests to determine suitable sampling depths in the three bands: fresh water, freshwater-seawater interface and salt water.

## RESULTS AND DISCUSSION

Vertical zoning was confirmed on the basis of electrical conductivity logs, with salinity being used to differentiate the three bands of fresh water, freshwater-seawater interface and salt water. The thickness of the freshwater zone ranges from 25–35 m, diminishing towards the coast. The thickness of the freshwater-seawater interface was between 20 and 30 m in the boreholes furthest from the sea, narrowing markedly towards the coast where it was slightly less than 10 m. The salt water zone began at a depth of between 40 and 50 m (Sánchez Martos et al., 2007; Jorreto et al., 2009). The physico-chemical data describe a zonation coherent with the data from the borehole logs: fresh water (electrical conductivity less than 6 mS/cm, with a sodium-calcium chloride-sulphate facies), freshwater-seawater interface (salinity from 15–30 mS/cm, sodium chloride facies) and saltwater (salinity of 45–57 mS/cm, sodium chloride facies (Tab. 1).

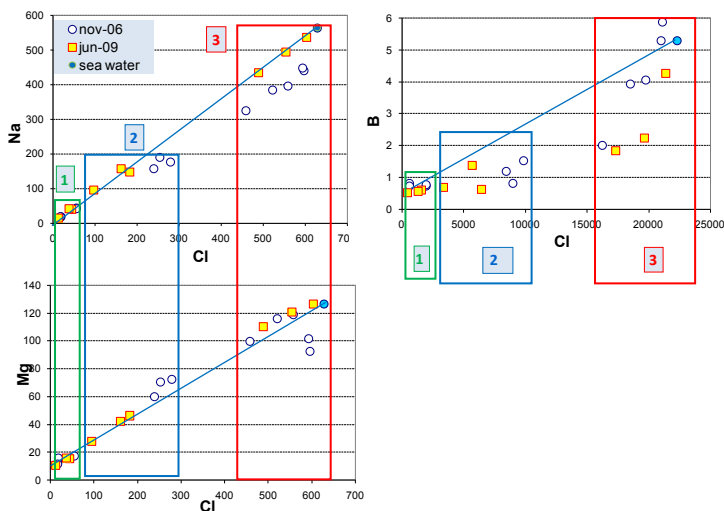
**Table 1** Summary of the main characteristics of the three water bands. Concentrations are in mg/L, E.C.: electrical conductivity (S/cm), (1): mean (2): standard deviation.

Zone	Data	E.C.	Na	K	Ca	Mg	Cl	NO <sub>3</sub>	SO <sub>4</sub>	HCO <sub>3</sub>	B
Fresh water	5	4.3	499.0	20.1	286.1	158.8	768.3	71.5	987.6	374.2	0.8 (1)
		0.9	206.0	7.3	60.9	25.7	408.5	9.1	54.1	14.4	0.0 (2)
Interface	9	17.4	2679.7	52.7	564.0	497.8	5349.8	41.4	1438.5	348.6	1.0 (1)
		8.6	1334.9	29.0	363.3	261.8	3122.9	12.7	255.8	30.6	0.3 (2)
Salt water	8	52.0	9933.6	363.4	796.2	1346.8	19379.5	0.5	2634.8	348.7	4.2 (1)
		4.5	1401.9	67.8	631.1	134.9	1758.0	0.0	272.9	51.1	1.3 (2)

The water in the fresh water band contained the highest nitrate concentrations, varying from 60–70 mg/L. The Andarax delta is an area of intensive agriculture, and this favours elevated nitrate

concentrations. Nitrate concentrations in the samples representing the freshwater-seawater interface were lower (23–54 mg/L), and they were practically zero in the saltwater band.

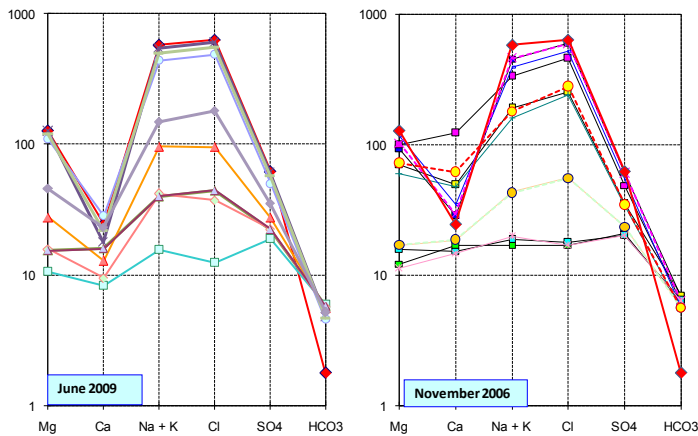
Samples corresponding to the freshwater-seawater interface had diverse chemical compositions (Tab. 1) due to the variety of processes associated with fresh water-seawater mixing. Considering chloride as a conservative ion, these processes were identified by plotting the relationships between Cl-Na and Cl-Mg and showing the theoretical line of mixing between fresh water and seawater (Figure 3).



**Figure 3.** Ratio of Cl/Na (meq/L) Cl/Mg (meq/L) and Cl/B (mg/L). The composition of seawater and the theoretical line of mixing between fresh water and seawater are shown. Three types of water are defined: (1) fresh water, (2) freshwater-seawater interface y (3) salt water.

Figure 3 shows the deviation in sodium content from the theoretical line of mixing that indicates a deficit, represented by the blue line. In terms of the relationship between Cl and Mg (Figure 3), there is a series of points that do not fall along the line of theoretical mixing, which indicate an "excess" of Mg. This Mg excess and Na deficit can be interpreted as due to ion exchange, which modifies the chemical composition of the mixing water. The same process is observed between Cl and B, where boron concentrations are less than expected for a mixture of fresh water-seawater. This ion exchange and ion absorption of Li and B has been studied for the Andarax delta (Sánchez Martos et al., 2002), in addition to the content of  $\delta^{11}\text{B}$ , which is attributed to differential enrichment caused by the absorption of boron by the lutitic aquifer matrix. Ion exchange causes a decrease in the B/Cl ratio (Morell et al., 2008). These ion exchange processes are indicated in Figure 4, where it can be seen that they especially affect the sampling points corresponding to salt water and the freshwater-seawater interface. These points exhibit a marked similarity with seawater, except in terms of the cations Mg and Na), which show slight variations up or down.

Analysis of the two surveys separately highlights clear differences between them (Figure 4). Data collected in November 2006 are more variable, with lower values recorded at the points corresponding to "fresh water", as well as at points in the freshwater-seawater interface.



**Figure 4.** Schoeller Berkaloff diagram, showing chemical data for the two surveys separately.

The chemistry of the deeper and more saline samples taken in June 2009 is more homogeneous (interface and salt water), and indicates a composition very similar to that of seawater. This homogeneity is linked to the exploitation of seawater by the desalination plant, which began to operate continuously during 2009. This collection of seawater mobilized the water in the salt-water band and modified the potentials and salinity (Jorreto et al., 2009), thus reducing the variability in the water chemistry of the interface and giving rise to ion ratios very similar to that of seawater.

### FINAL CONSIDERATIONS

To understand the hydrogeochemical processes taking place in coastal detritic aquifers, various tools are required (detailed surveys of the borehole column, and electrical conductivity and temperature logging), and a monitoring network must be in place to take borehole samples at different depths. This is fundamental because the aquifers undergo frequent changes in facies that lead to the development of levels with different permeability. Added to this, the presence of salt deposits of marine origin significantly affects the hydrogeochemical evolution of the water, making it more difficult to elucidate the hydrogeochemical processes that are directly related to marine intrusion. In the Andarax delta, several ion exchange processes have been identified that are a consequence of the lutitic intercalations in the aquifer matrix, including boron. Ion exchange occurs especially in the deeper, more saline bands, and so this is where the variability of the water is greatest.

One final comment is that the homogeneity of the deeper waters is probably a consequence of the seawater collection by the desalination plant, whereby the water in the deepest band exhibits ion ratios very similar to that of seawater.

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