The Second International Conference on Saltwater Intrusion and Coastal Aquifers —
Monitoring, Modeling, and Management. Mérida, Yucatán, México, March 30 - April 2, 2003

Delineating the saltwater wedge in two carbonate aquifers in Mallorca (Spain)

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ABSTRACT

Delineating the actual location and shape of the freshwater-saltwater transition zone is a prerequisite for long-term prediction of groundwater quality in coastal regions. Two sites with saltwater intrusion problems in Mallorca are currently investigated within the framework of the European research project ALIANCE. Whereas the extent of the saltwater intrusion is well known and easy to understand for one of the sites (Campos), the saltwater intrusion problem of the second site (Pollensa) is far more complex and much less understood. The Campos site is located in the south of the island in Miocene reefal units. The aquifer is affected by saltwater intrusion over an estimated surface area of 150 km^2. The Pollensa site is situated in the north-eastern part of the island in a karstified and fractured limestone of Jurassic Age.

FIRST FIELD CAMPAIGN

The first field campaign in February 2002 consisted mainly of logging existing wells for electrical conductivity and temperature. A total of 22 holes were logged in both the Campos and the Pollensa site. An important aspect of these existing wells is that all of them are equipped with long screened interval, usually over the entire saturated thickness of the aquifer. The conductivity profiles at the Campos site were more or less as expected from the hydrogeology. Fresher water overlies saltwater with a conductivity of 53000 µS/cm at 25°C, which is the conductivity of the Mediterranean Sea (Figure 1, right profile). At the Pollensa site, conductivity profiles were harder to interpret. The average conductivity profile recorded showed a very straight line of lower conductivity (1500-2000 µS/cm) in the upper part of the screened interval, followed by a steady increase to about 7000 µS/cm in the lower part of the screened interface (Figure 1, left profile). A separation of freshwater and saltwater could not be observed. It seemed unlikely that this reflects the natural groundwater situation, as these boreholes are all close to the main recharge area of the island, the Serra de Tramuntana. We hypothesised that recordings at the north-eastern site were affected by ambient flow within the boreholes, caused by different piezometric heads within the long screened well sections. The fully screened boreholes are supposed to short-circuit different fractures, respectively high transmissive zones with different hydraulic heads, at various depths. Consequently, the natural formation fluid distribution is no longer visible or even no longer existent. Insight into the real saltwater wedge extension is therefore difficult to obtain with such a classical approach.

TESTING-WHILE DRILLING OPERATION

For this reason a testing-while-drilling procedure was developed and applied during drilling of the first test hole in September 2002, called MP1 (Mallorca Pollensa 1), to a depth of 100 m. Sulphorhodamine B tracer was added to the drilling fluid with an average concentration of 200 ppb to allow for back-calculation of the groundwater composition within water samples. Tracer concentrations of the drilling fluid and the groundwater samples were measured on site with a GGUN-FL30 Fluorimeter (Schnegg and Doerfliger, 1997). When a permeable zone was encountered, drilling was stopped and a "pumppacker" was installed at the lower end of the drill-string to isolate the permeable stretch. This device consists of a single packer combined with a slim pump. Water was pumped at a constant rate until the tracer concentration was sufficiently low to take a good groundwater sample. After completion of the sampling and testing, the packer/pump system was remounted and drilling was continued until the next permeable zone was reached. Five different zones were tested and samples were taken. Due to the large amount of drilling fluid applied (total 233 m^3), the favoured 1% fraction of drilling fluid within the groundwater sample could not be reached, even after several hours of pumping. Therefore, a higher mixing ratio between 4 and 16% was allowed. From the analyses of major anions and cations, two different water types could be distinguished in agreement with the change in geology from Jurassic Lias to Rhaetian (Figure 2). In contrast to the fully screened wells, the testing-while-drilling procedure allowed to investigate the natural groundwater situation.

FLOWMETER LOGGING

After completion of MP1 the open borehole was pumped for about 1 day with approx. 70 l/min. Then an EC conductivity log was taken and compared with the log at a neighbouring screened well from the February campaign (Figure 3). Most striking was the fact that overall conductivity is lower and that conductivity decreases with depth. Again this was an indication that the profiles from the long screened intervals do not represent the formation fluid distribution as it is seen straight after drilling.

The flowmeter logging experiment consisted of several runs with different cable speeds without pumping and several runs with different cable speeds for a discharge rate of 10 l/min and a discharge rate of 20 l/min. The combined data interpretation indicated zones of different electrical conductivity and zones with different heads as hypothesised before. Different inflow zones could be distinguished, and a first estimation of their relative flow rates could be obtained. It could be concluded that flow within different permeable zones reacted differently under the same applied stress. It was not possible to quantify the head differences between different permeable zones.

FLUID LOGGING

Two fluid logging experiments have been performed. One experiment took place when the borehole was 40 m deep, the second when the borehole was completed. The fluid logging experiments followed the method of (Tsang et al. 1990) for a formation with slightly brackish water or saltwater. It consisted of flushing the borehole with a known volume of freshwater. After flushing, the borehole was logged several times to follow the progressive inflow from flowing features of the fractured formation. The first log was without pumping, the other logs are taken after some time of pumping so that steady state can be assumed. The results from both experiments clearly show that there is already inflow between flushing and before pumping, a clear proof of ambient flow (Figure 4).

From a first rough interpretation putting together fluid logging and flowmeter logging, transmissivity values for the flowing features in MP1 were derived. To stop spoiling the electrical conductivity profile by ambient flow a temporary packer made of PVC-hose was installed to a depth of 84 m.

OPTIMISATION/FUTURE ADAPTATIONS

The testing-while-drilling method gave us a quick insight into the main fluid characteristics and proved even before the borehole was finished that delineating the freshwater/saltwater interface is as difficult as expected. The first drilled borehole did not show any sign of saltwater up to a depth of 100 m, on the contrary the water conductivity decreased with depth. The quantification of the ambient flow was derived from active tests right after completion of the hole. The interpretation of these tests would be easier if more hydraulic data on the fractured zones in the borehole would be available, some of which can only be taken during drilling. The most important of these is the steady state head. For this purpose the "pumppacker" has been equipped with a very sensitive pressure probe, so that during the pumping time needed to retrieve a sample, a small single fracture pumping test can be carried out and a recovery to steady state head can be monitored for this fracture. The information from this in situ testing may then be compared to the transmissivities derived from the fluid logging interpretation.

References

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Tsang, C. F., P. Hufschmied, and F. V. Hale. 1990. Determination of Fracture Inflow Parameters with a Borehole Fluid Conductivity Logging Method. Water Resources Research **26**:561-578.

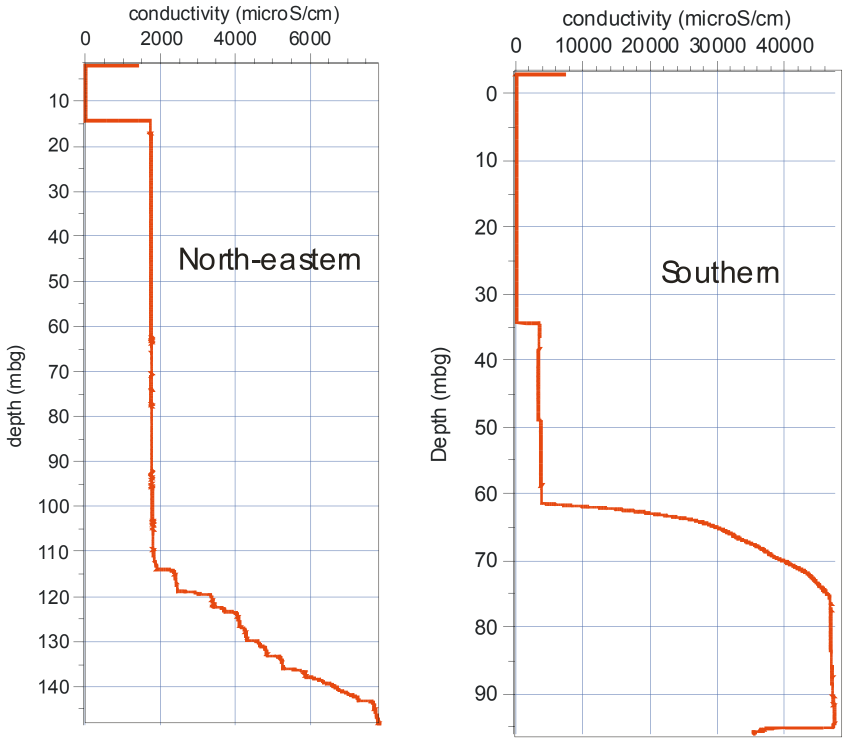

Figure 1 Typical recorded EC logs for both sites during the February 02 campaign

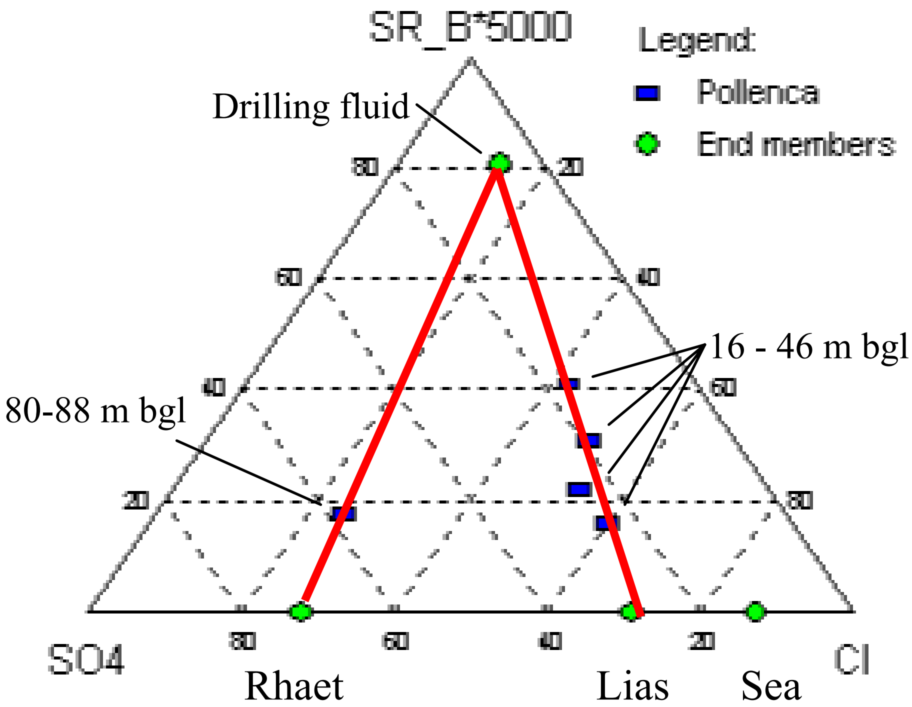

Figure 2 Mixing of drilling fluid with "Rhaet" and "Lias" groundwater at various depths of drilling.

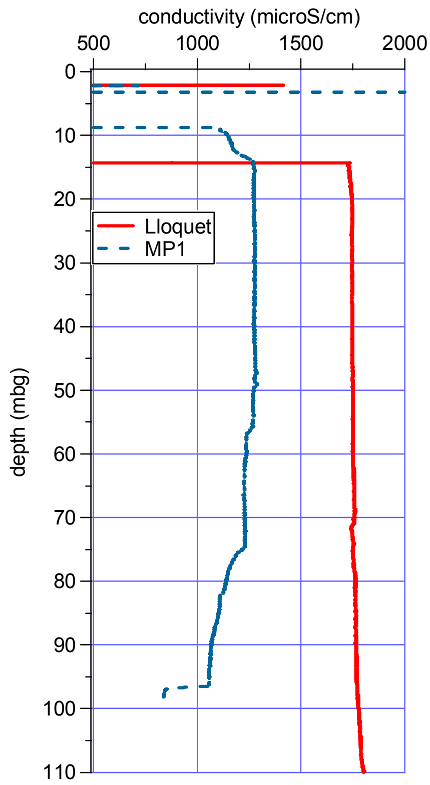

Figure 3 Comparison of a typical slotted screen EC log (lloquet) and the EC log of the newly drilled hole after several hours of pumping

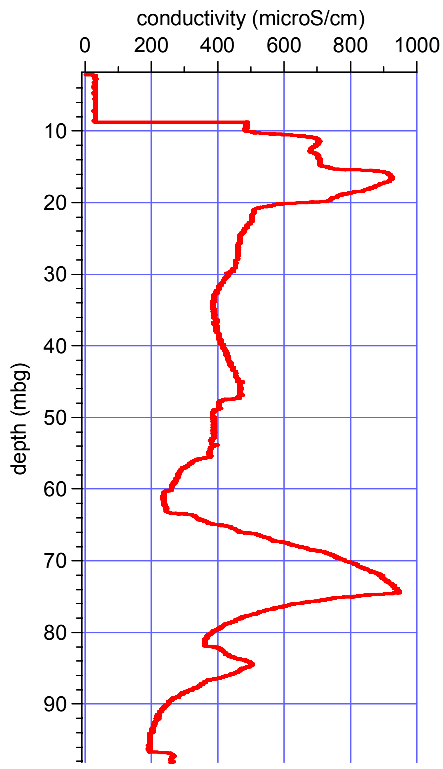

Figure 4 EC log of MP1 (notice the conductivity scale) after flushing with freshwater and a time laps of about 1 hour. There are clear signs of ambient flow at a depth of 47m, 74m, and 84m.