HYDROCHEMICAL CHARACTERISATION OF A COASTAL AQUIFER AT THE GERMAN NORTH-SEA COAST

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Abstract.
In an ongoing project a Coastal Aquifer Testfield (CAT-Field) was installed for hydrological investigations at the German North Sea coast. Because of the partly coarse grained sediments the region seems to be suitable and may be interesting for future groundwater exploitation. To determine their possible influences is the aim of an interdisciplinary project. For the interpretation of the geochemical processes occurring in the salt- freshwater transition zone and during salinization, field data are compared with results from laboratory experiments and numerical calculations. Different types of groundwater are characterised by their geochemical pattern. Possible mechanisms for the formation of present $NaHCO_3$ waters are Calcite precipitation and exchanger reactions during refreshening of the aquifer. These are briefly discussed with respect to results of column experiments, a two-dimensional flow chamber experiment and their geochemical modelling with the computer programs PHREEQC (Parkhurst and Appelo, 1999) and Processing SHEMAT (Kühn and Chiang, 2000).

Keywords: coastal aquifer, geochemical processes, saltwater intrusion, geochemical modelling, exchanger processes, calcite precipitation

INTRODUCTION

The underground of Northwest Germany is characterised by a porous aquifer system, the adjacent tidal flat coast and a connected saltwater intrusion. A speciality is a system of glacigene channels which were refilled at the end of the Elster ice age (Kuster and Meyer, 1979). Because of their partly coarse grained filling, the region seems to be suitable and may be interesting for a future groundwater exploitation. The determination of possible influences of the exploitation due to saltwater upconing, a typical problem of coastal regions (Das Gupta and Yapa, 1982; El-Baruni, 1995), is the object of an interdisciplinary project. Therefore a Coastal Aquifer Testfield (CAT-Field) was determined. The CAT-Field is bordered by the Elbe and Weser estuaries and the tidal flat coast between the cities Bremerhaven and Cuxhaven in the north-western part of Germany (Figure 1). The aim of the project is a quantitative prediction of the amount and quality of the groundwater for this region. This prognosis will be based on numerical simulations of flow and transport in the aquifer. Necessary data is delivered by different geophysical, hydro-/geochemical and hydrological investigations. The attained results from studied methods, effects and phenomena should be transferred to other regions with saltwater intrusion.

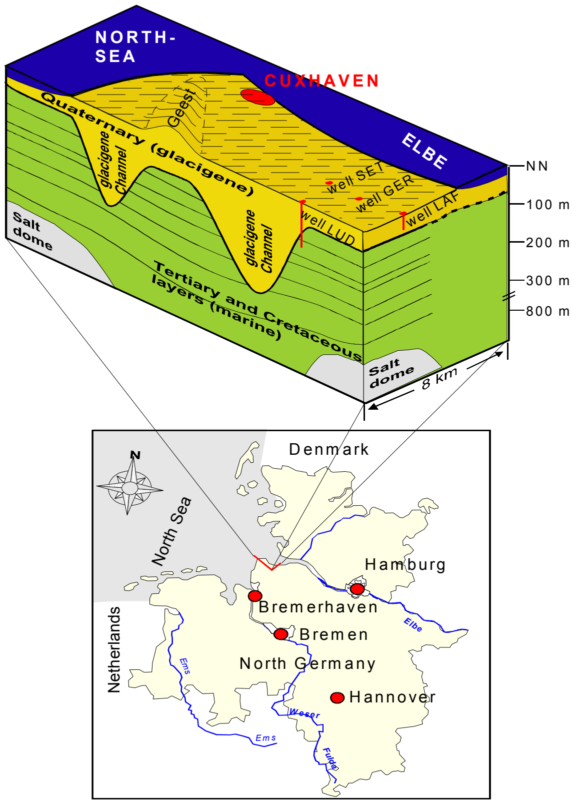

Figure 1 Location and the general geological setting of the CAT-Field. Please notice exaggerated and discontinuous scale.

The examination of the geology, hydrogeology and hydrochemistry of the CAT-Field was done by an interdisciplinary working group at

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the Institute for Applied Geosciences in Hannover in cooperation with other research institutes as for example the University of Bremen, where e.g. column and flow chamber experiments were performed. The present report will focus on these investigations for a hydrogeochemical characterisation of the CAT-Field aquifer and their generating processes. These will be determined by a comparison of field data with results of laboratory and numerical simulations.

METHOD

Field Investigations

For the determination of the geology and the depending geochemical and hydrological conditions more than 40 geological screw drillings up to a depth of 90 m were performed in the investigation area. During drilling works the geology was determined by a grain analysis of the drilling mud. The position of the salt-freshwater transition zone – so far unknown - was determined during drilling. This was done by dilution of a constant sediment sample with 100 ml distilled water and measurement of the electric conductivity of the obtained suspension (Wagenschein, 2002). To provide hydrochemical sampling, some of the geological drills were screened in different depths. Together with existing wells in the CAT-Field there are more than 40 sampling and observation points down to a depth of 190 m. Groundwater samples were taken at different times of the year and acidified for conservation. Sensitive parameters as pH, Eh, O_2-saturation and temperature were determined immediately by electrodes in a flow chamber, alkalinity by titration after filtration according Grasshoff et al. (1983).

In November 2001 the first of three planned research drills was brought down in the flank of a glacigene channel (well LUD, see Figure 1). The in most parts flush drilled well reaches a depth of 120 m and is completely screened (Binot et al., 2002). During drilling about 40 m of ram cores were gained and stored frozen at -23°C until sampling to preserve from autooxidation. Samples of the solid phase (esp. in the transition zone) are analysed by RFA and X-ray diffraction. Porewater is gained by centrifugation of the complete samples under argon atmosphere. After the determination of pH, Eh and alkalinity the samples are acidified.

Laboratory analyses of groundwater and porewater samples were performed for up to 40 components. Cation concentrations were determined by inductively coupled plasma atom adsorption spectroscopy (ICP-AES), anion concentrations by ion chromatography.

Experimental and Numerical Modelling

For the determination of the processes leading to the determined hydrochemical characteristics the obtained field data were compared with results of laboratory simulations and their numerical model. The processes occurring during the intrusion and refreshening of the aquifer were simulated in column experiments. The columns were filled with sediments from the CAT-Field aquifer and conditioned with artificial groundwater. After the condition phase they were flushed with artificial seawater and later with groundwater again. Experimental setup and results can be found more detailed in Panteleit et al. (2001b).

For the determination of processes occurring in the stable transition zone a two-dimensional sand tank experiment has been developed (Figure 2). Original sediments from the aquifer were filled in different layers in a perspex lined box, following an adjusted hydraulic gradient groundwater flows through the box. The flow direction of the induced saltwater intrusion is directed versus the hydraulic gradient and reaches a steady state after some weeks. First results of the intrusion phase of the saltwater are described together with the expe-

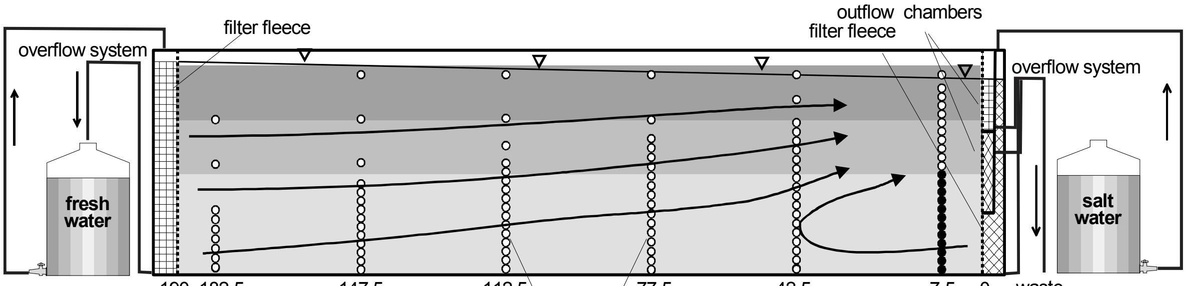

Figure 2 Experimental set up of the flow chamber experiment. Freshwater flows according to the induced hydraulic gradient toward two outflow chambers, while in the deeper part a density driven saltwater intrusion is induced.

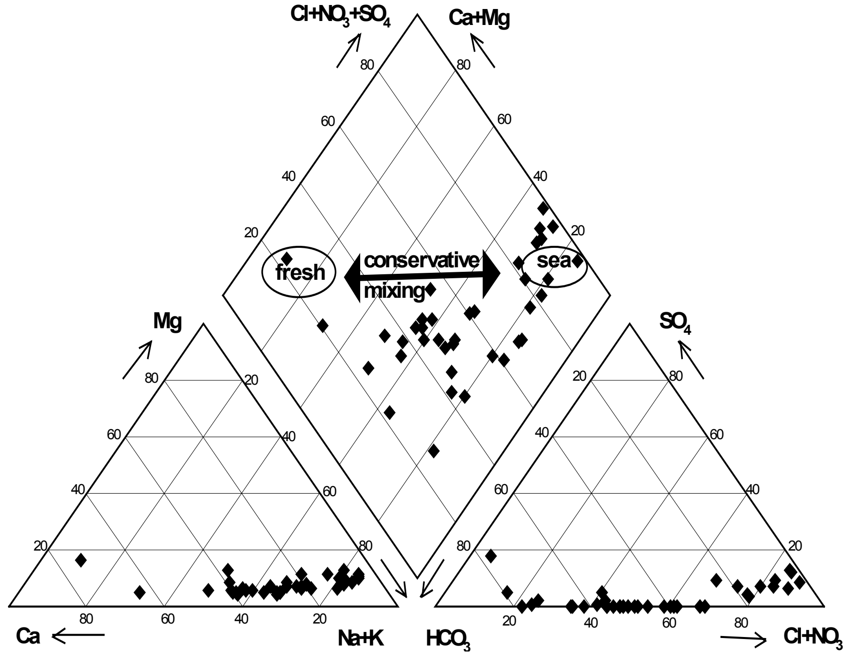

Figure 3 Piper plot showing composition of 40 groundwater samples from different locations and depths in the CAT-Filed, representing the transition from fresh- to saltwater.

rimental setup in Panteleit et al., (in press). Samples from column and sand tank experiments were taken at different positions and analysed as described above for the field samples. Exchanger reactions of the column experiments and a horizontal intrusion into the sand tank have been modelled using the computer program PREEQC (Parkhurst and Appelo, 1999). Input parameters were gained by a tracer experiment (hydraulic data) and CsCl-extraction of the sediment (exchanger occupancy) as described in Panteleit et al., (2001a). The two-dimensional flow in the sand tank has been modelled with Processing SHEMAT (Kühn and Chiang, 2000). In the next step the coupling of the chemistry to the hydraulic model will be done.

RESULTS

Ratios of major ions are displayed in a Piper diagram (Figure 3). Seawater is characterised by a high content of Chloride. As the Chloride ion does not interact with other ions or the solid phase it can be used as a proxy for the seawater. Accordingly the anion triangle of the Piper diagram gives a good reflection of the saltwater intrusion in the CAT-Field. While all samples are characterised by very low Sulfate concentrations, Hydrogencarbonate is the dominating anion at lower depths and close to the Geest, regions which are flushed by freshwater. Higher Chloride ratios can be found in greater depths and close to the coastline. The transition between these two watertypes is smooth and continuous suggesting a rather wide transition zone than a sharp interface between fresh and saltwater. This can also be seen when the Chloride concentration of three multilevel wells (Figure 1) is displayed versus depth (Figure 5). The beginning of the transition zone is

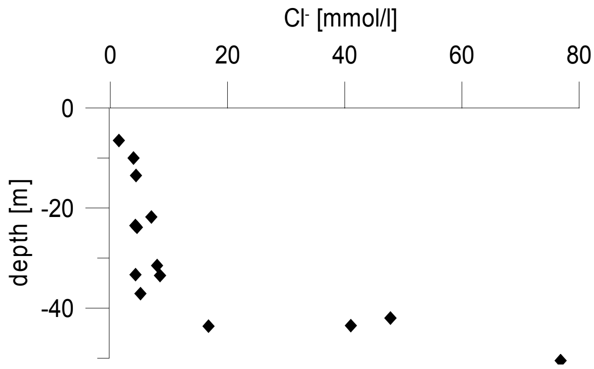

Figure 4 Chloride concentration versus. depth from groundwater samples from multilevel wells (GER, LAF, SET; see Fig. 1) at the CAT-Field

determined by the increasing concentrations from 35 bsl. on, while in the overlying freshwater the salt content is constant at more or less low levels. The beginning of the transition zone at 35 m bsl. in a distance of about 4 km from the coast is in good accordance with data from other wells (Kringel, BRG-Hannover, unpublished data), during drilling conductivity measurements (Wagenschein, 2002) and airborne resistivity measurements (Siemon et al., 2001). All together these data show a dip of the transition zone of about 8,5 ‰ land inwards beneath the marsh areas.

In the cation composition the groundwater samples are generally characterised by low Magnesium ratios. Fresh water samples with high Hydrogencarbonate ratio are dominated by Calcium and represent the $CaHCO_3$ watertype. The samples originating from sample points very close to the coastline or from greater depths have the highest Chloride ratios and are dominated by Sodium. They are of a NaCl type and represent the saltwater endmember of the transition. But in contrast to the anion composition the transition between these two endmembers is not continuous with regard to the anion composition. Most samples are dominated by Sodium, while only very few show a Calcium content higher than 50%. This results in an excursion from the ideal (conservative) mixing line between salt and freshwater towards a $NaHCO_3$ type (combined diagram in Figure 3). In a zone parallel to the coastline Wîndelberg (2001) determined also a $NaHCO_3$ water type in the nearby region of Bremerhaven. This water type was surrounded by a $CaHCO_3$ and the NaCl type, thus it seems also to represent the transition between these two water types. For the explanation of this enrichment of Sodium in the waters there are two possible mechanisms to discuss.

The first mechanism is the depletion of Calcium due to Calcite precipitation in the transition zone between fresh– and seawater. A precipitation of Calcite is also observed by Magaritz and Luzier (1985) in an aquifer of comparable mineralogy. A speciation of the groundwater samples from the CAT-Field with PHREEQC (Parkhurst and Appelo, 1999) show that all water samples are saturated with Calcite. Thus a precipitation of Calcite might be a possible explanation for the minor importance of Calcium in the mixing waters. This mechanism could be verified by the detection of autigene carbonates in the solid phase. The outstanding analysis of the solid phase of the gained sediment cores will be performed in the near future.

Cation analysis of pore waters from the sand tank model show likewise a dominating sodium fraction. But as anion analysis has not yet been completely performed it is not necessarily that this results in a $NaHCO_3$ type water. A quick salinization to higher stages might be as well the reason for the lack of Calcium dominated waters. The previewed analysis of the solid phase of the laboratory aquifer will give further information if Calcite precipitates in the transition zone or not.

Another possible mechanism resulting in $NaHCO_3$ waters is an exchange of adsorbed Sodium by Calcium. This exchanger reaction usually occurs during the refreshening of a sediment formerly in contact with saltwater. Accordingly it was found during the refreshening stage of the performed column experiments as well as in field observations for example by (Vandenbohede and Lebbe, 2002) in the Belgian coastal plain. The process of exchanger reactions requires a mobile transition zone. Thus the present situations could not be a steady state concerning the water balance. A possible mechanism for this unsteady state is proposed by Hahn (1991), who reported also the occurrence of $NaHCO_3$ type waters in the Wittmund area, west of the river Weser. Hahn (1991) traces a movement of the transition zone back to climatic changes: Groundwater recharge decreased during the Subboreal and resulted in a saltwater intrusion 2500 – 3000 years ago. The refreshening was induced by the rainy Subatlantic period and later by diking of the marsh areas. This assumed cause for the pushed-back saltwater intrusion is supported for the Wittmund area by the determined ages of the water bodies. If the $NaHCO_3$ waters in the CAT-Field originate also from the refreshening of a Subboreal salinization is debatable. A flow velocity of at least 0,1 m/d was obtained by current groundwater flow tests (unpublished PHREALOG measurements). If this value is presumed to be more or less constant over time a refreshening phase of a Subboreal salinization should be terminated and the products of the exchanger reactions not longer be detectable. The age of the water masses could give further information to solve the problem. Samples for dating have been taken, the results can be expected this summer.

OUTLOOK

First results from geochemical analysis of groundwater in the fresh-saltwater transition zone have been presented and were used for the characterization of different water types. Additional groundwater samples have been taken. These will be used for validation of the present results and the possible definition of further water types. With the additional sample points a determination of the regional distribution of these water types will be possible.

Especially previewed detailed sampling over depth together with analyses from the solid phase of the installed research well promise new information about the processes in the transition zone. These are also supposed to be reflected in the two-dimensional flow chamber. Detailed analyses of the porewater and the solid phase of the sand tank are done. The processes occurring in the laboratory experiment will be modelled with the computer program Processing SHEMAT (Kühn and Chiang, 2000) and used for the interpretation of the field data.

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