

## **Pore water analyses of low-permeability sediments as a tool for reconstruction of hydrological processes.**

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### **ABSTRACT**

The groundwater quality of coastal areas is strongly influenced by changes in the hydrological boundary conditions, such as coastline configuration and climatic conditions. As groundwater quality patterns take a long time to adapt to the new boundary conditions, the effects of these changes can still be noticed today. For example, large amounts of saline groundwater are still found below areas that were formerly covered by the sea.

The reconstruction of former hydrological processes from water quality measurements in observation wells in aquifers is often difficult as a result of complex flow paths. In low-permeability layers (clay, peat), however, flow is small or even absent. Transport of solutes in such layers is mainly determined by diffusion, which is a very slow process. This means that the effect of changing hydrological conditions on the chemical and isotopic composition of the pore water will be preserved for periods of up to thousands of years. This makes low-permeability sediments excellent targets for tracing former hydrological processes.

This contribution reports on five pore water profiles from shallow, Holocene (< 10 ka BP) sediments in the coastal plain of the Netherlands and one profile from the bottom of the North Sea (figure 1). Figure 2 shows the pore water concentration profiles at the six locations. In the following sections, the processes that have led to the observed concentration patterns will be discussed qualitatively for each of these sites.

#### *Site 1: evaporation followed by freshening*

Chloride concentrations between 3.8 and 4.8 m below the surface exceed that of ocean water (Cl = 566 mmol/l) by ~ 10 % and that of local sea water by ~ 50 %. Post et al. [submitted] identified evaporation of sea water in a salt marsh setting as the responsible process for these high concentrations. Their model uses the change of the isotopic composition of  $^2\text{H}$  and  $^{18}\text{O}$  during evaporation in combination with observed relations between  $^2\text{H}$ ,  $^{18}\text{O}$  and Cl to calculate both (1) the final composition of the evaporated water and (2) the initial composition of the sea water prior to evaporation. The model corroborates measurements that show that the salinity of the Wadden Sea has decreased over the past centuries due to increased fresh water inflow. Freshening of the clay layer started some 170 years ago when the polder area was reclaimed from the sea. Positive  $\delta^{37}\text{Cl}$  values reveal that diffusion is the dominant transport mechanism but a satisfactory fit between modeled values and field data could only be obtained by assuming a downward seepage rate of 5.8 mm/yr. This contrasts with the upward seepage rate that follows from regional flow models [Oude Essink, in press], which shows that detailed measurements such as these are required to understand the hydrological processes that operate on a local scale.



Figure 1: Map of the Netherlands showing the location of the pore water profiles.

*Site 2: infiltration along preferential flow paths*

This profile [Van Rossum, 1998] is located in the central part of the Netherlands, south of Amsterdam. The groundwater level in the confining unit is 2.1 meters higher than the hydraulic head in the underlying aquifer, which implies that groundwater recharge by precipitation and surface water occurs. Chloride concentrations in the marine clays however are still high, showing that flushing of these deposits has been negligible. Diffusion of Cl into the overlying peat seems to take place. As the groundwater below the confining unit has a lower Cl concentration, recharge is expected to take place along preferential flow paths such as sandy tidal creeks that dissect the clay layer [Van Rossum, 1998].

*Site 3: flushing by downward flow*

This site is located 3.5 km from site 2. Similar to the previous site, there is a difference of  $\sim 2$  m between the groundwater level in the Holocene deposits and the hydraulic head in the underlying aquifer. Contrary to site 2, the marine clays here have been largely flushed by infiltrating fresh water. A peculiar peak of the chloride concentration is present in the peat layer at the base of the confining unit. Apparently, flushing of this unit, which is often known to have a very low permeability due to compaction, has not occurred. This would mean that flow in the overlying low-permeability deposits is not strictly vertical, an often-made assumption in regional-scale hydrological flow models. The elevated Cl concentrations also extend into the underlying aquifer. Similar patterns are observed in electrical conductivity logs from cone penetration tests in other parts of the Dutch coastal areas.

*Site 4: flushing by upward flow*

This profile was obtained from a sequence consisting of Holocene marine clays and peat that is located at the foot of a plateau that has an elevation of some meters above the adjacent polder area. Topography-driven groundwater flow is directed towards the polder area where discharge through the Holocene confining

units occurs. Chloride concentrations of the pore water in these units are within the range of the fresh groundwater in the underlying aquifer which implies that the original saline pore water has been completely flushed. EC in the lower clay unit is conspicuously higher than in the ambient groundwater but is not related to Cl. No additional data are available to explain this peak. Slightly increased Cl concentrations in the upper clay unit possibly represent small quantities of remaining salt.

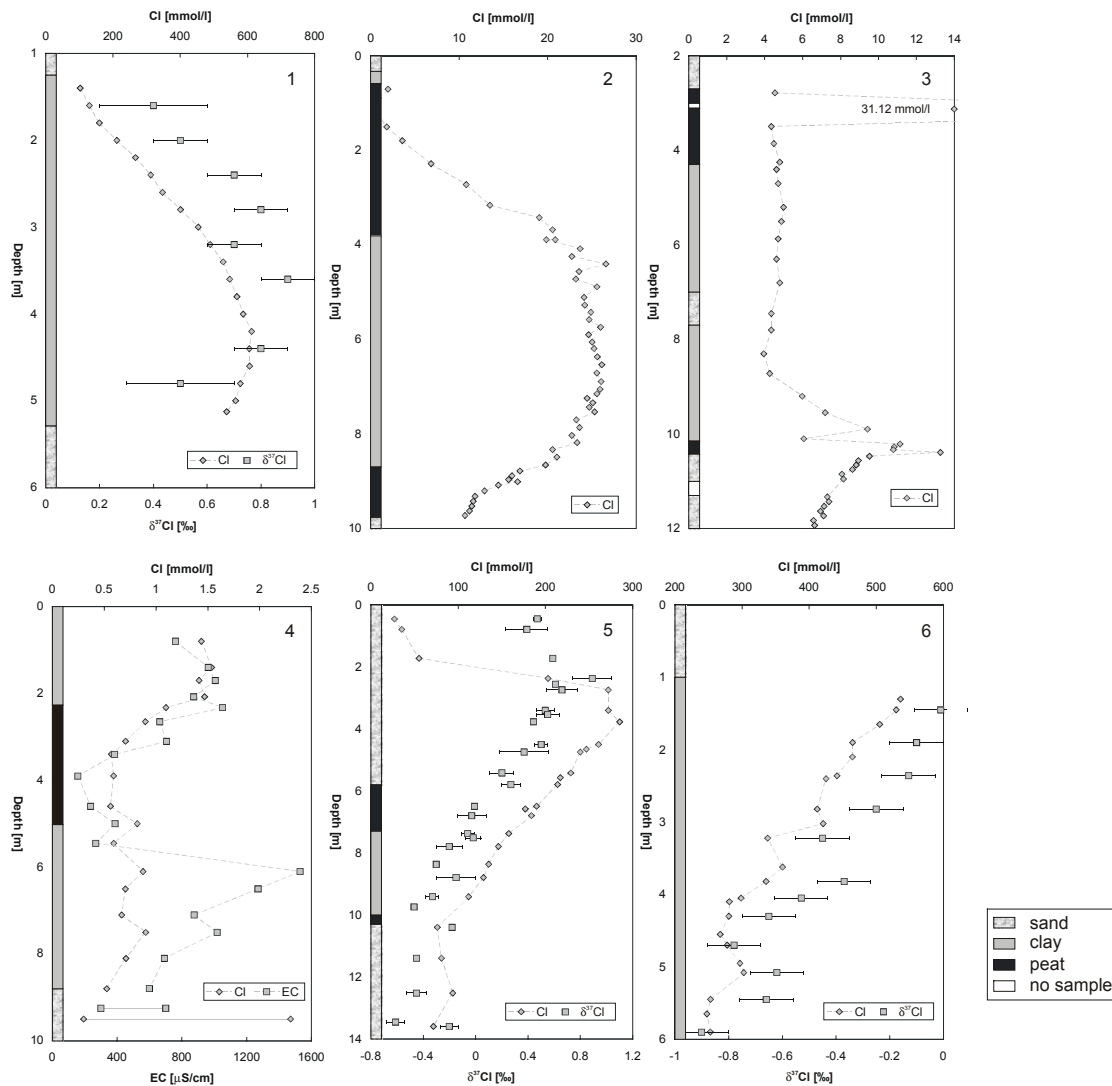


Figure 2: Pore water profiles. See figure 1 for their locations. Data from Post et al. [submitted] (site 1), Van Rossum [1998] (site 2), Kortekaas [2001] (site 3), Beekman [1991] (site 4) and Post et al. [2000] (site 6). Note the difference in scale.

*Site 5: salinization and freshening with coeval deposition*

This site is located below a former inland-sea that became fresh when it was dammed from the sea in 1932. Diffusion of salt into the previously fresh pore waters started when the sea first invaded the area in 1570 AD, which explains the downward decrease of Cl from its peak concentration of 285 mmol at 3.75 m below the lake bottom. The decreasing Cl concentrations from this depth towards the top of the profile are caused by back-diffusion since 1932 when the lake water became fresh again. Similar profiles were measured by Volker [1951] in other parts of the IJsselmeer area. Beekman [1991] found that the observed Cl and especially  $\delta^{37}\text{Cl}$  could only be modeled correctly when sedimentation and periodic changes of salinity were taken into account.

### *Site 6: salinization and anion exclusion*

The sediment at this location consists of a lacustrine clay that dates from the Early Weichselian (~ 100 kA BP). Since its deposition, the area was exposed until 9 kA BP when it was flooded by the North Sea. The decreasing Cl concentration with depth clearly shows that the original fresh water is slowly salinized by diffusion. The negative  $\delta^{37}\text{Cl}$  values confirm this. Post et al [2000] found that the diffusion coefficient of Cl is 10 times lower than that of  $\text{H}_2\text{O}$  and attributed this to the effects of anion exclusion.

The results of this study show that low-permeability sediments contain valuable information from which the former hydrological processes and boundary conditions can be reconstructed. The measurement of multiple parameters is a powerful means to identify such processes as evaporation (Cl in combination with  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ ), advection and sedimentation (Cl in combination with  $\delta^{37}\text{Cl}$ ) or anion exclusion (Cl and  $\delta^{18}\text{O}$ ). Reconstruction of the transport processes that shaped the observed water quality patterns in the course of many thousands of years also help in quantifying the effective hydraulic properties of these aquitards and the role of preferential flow paths, such as the sandy channels that are ubiquitous in the former tidal flat environments of the Dutch coastal area.

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