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Combining numerical modeling and isotope data to assess reductive dechlorination and diffusion in clay tills

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Enhanced Reductive Dechlorination (ERD) has been successfully used in high permeability media, such as sand aquifers, and is considered to be a promising technology for low permeability settings. One of the main challenges in low-permeability settings is to obtain good contact between the injected bacteria and electron donor and the contaminants trapped in the matrix. The objective of this study is to assess whether the degradation processes take place only in higher permeability zones in the clay till such as sand lenses or stringers, or if degradation processes also develop within the clay till matrix. Isotope fractionation data, biogeochemical data and numerical modelling is used to identify the zones in the clay till where natural dechlorination has occurred. The results can be further combined with other data (molecular biological tools, pore size constrains, etc…) in order to identify the controlling parameters that allow degradation in the matrix.

Reactive transport models coupled with isotope fractionation are widely used to document natural attenuation along flowpathes in high permeability porous media. Isotope fractionation due to diffusion is often negligible in advection dominating systems, but diffusion is the dominant transport process in the clay matrix, and the heavier isotopes are expected to diffuse slower than the lighter ones. But it can be difficult to distinguish whether isotope fractionation is caused by diffusion or degradation. In the present work, modelling was used to investigate several conceptual models regarding dechlorination locations (in high permeability zones, in the whole matrix, in limited bioactive zones within the matrix). The model includes diffusion in the matrix, sequential dechlorination, isotope fractionation due to degradation and isotope fractionation due to diffusion in the clay matrix.

At Vadsby, Hedehusene, Denmark, chlorinated solvents were spilled during the 1960-70's, resulting in contamination of the clay till and the underlying sandy layer (15 meters below surface). The clay till is heavily contaminated between 4 and 15 mbs, both with the mother compounds PCE/TCE and TCA and the daughter products (DCE, VC, ethene, DCA), indicating the occurrence of natural dechlorination of both PCE/TCE and TCA. Intact core samples of length 0.5m have been collected from the source zone (between 6 and 12 mbs). Concentrations and stable isotope fractionation of the mother compounds and their daughter products, as well as redox parameters, fatty acids and microbial data, were analyzed with discrete sub-sampling along the cores. More samples (each 5 mm) were collected around the observed higher permeability zones such as sand lenses, sand stringers and fractures, where a higher degradation activity was expected.

In several cores, the concentration profiles of TCE and daughter products indicate that degradation is likely to have occurred in and around the high permeability features, as well as further within the clay matrix. The isotope data must be combined with numerical modelling to distinguish between transport processes (diffusion/sorption) and degradation, and support the identification of bioactive zones within the clay till. Improved understanding of reductive dechlorination in clay tills is useful for improving the reliability of risk assessment and the design of enhanced reductive dechlorination remediation schemes for chlorinated solvents.