Evaluation of environmental fracturing as a remediation aid in clayey till

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Background

Contaminated low-permeability sites are difficult to remediate, but require attention due to the long-term leaching threat that they pose to underlying groundwater, see Figure 1. Environmental fracturing offers assistance to remediation efforts at contaminated, low-permeability sites via creation of fracture networks and hence reduction of mass transport limitations set by diffusion in the low-permeability matrices /1-6/. The technology seems promising, but few studies provide direct documentation of fracture propagation patterns, spacing, and aperture /7-8/. Emphasis has been on indirectly measured permeability and short-term remediation enhancements /8-10/. Thus, the scope of

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**Figure 1: Concept of reverse diffusion.**

- Early contamination: contamination is transported through the clay via fractures and into the clay via diffusion.
  - \[ C_1 < C_0 \Rightarrow \text{Diffusion into clay} \]

- Present contamination: Contamination transport in fractures ceased (due to natural source depletion or effective remediation), resulting in reverse diffusion of contamination from the clay matrix into the fractures.
  - \[ C_1 > C_2 \Rightarrow \text{Diffusion out of clay (reverse diffusion)} \]
possible long-term remediation enhancements achievable via fracturing is uncertain, and accurate predictive modeling of expected remediation time-frames impracticable.

**Experimental work**

A pneumatic fracturing field study has been conducted at a clay till site in Denmark. The pilot study applied a novel package of methods to directly document fracturing effects, including injection of five tracers during fracturing: *rhodamine WT, uranium*, and *uvitex* (fluorescent tracers); *brilliant blue* (dye); and *bromide* (colorless). Subsequently, coring, augering, and excavation within the expected radius of fracturing influence were carried out to detect tracer-filled fractures and geologically characterize the site, see Figure 2.

![Field work and observations](image)

*Figure 2: Field work and observations in connection with site excavation. (top left) Manual scraping of profiles for use in geological characterization. (top right) Observation of natural fractures. (bottom left) Observation of tracer-filled fractures. (bottom right) Exposed tracer-filled fracture.*

A total of 102 m cores were retrieved. Fractures and tracer concentrations were identified via visual inspection (daylight, UV-light), extensive sampling and analysis.
Results

The tracers were well-suited for identification of induced/activated fracture distribution, as they allowed for an array of documentation methods to be employed successfully. The behavior of the tracers fluorescein and rhodamine WT may be extrapolated to support conjectures on expected transport and spreading of various reactants typically injected for in situ remediation efforts /11/.

![Figure 3: Photograph of tracer-filled fracture observations in a core sample taken 1 m from the fracturing borehole at approximately 3.5 m b.s. On the left a wide fracture is observed, while a thinner fracture is observed on the right.](image)

A mass balance for the distribution of tracers and a conceptual model for the induced fracture network have been established. Both illustrate that tracer was distributed within 2 m of the fracturing well, mainly in existing fractures; some naturally active, others opened via fracturing. The bulk of the tracer mass was located in the redox zone (3-4 m.b.s.), where natural fracture frequency is high. Spacing of observed tracer-filled fractures was much larger at deeper levels (4-8 m.b.s.) and thus not considered sufficient to aid removal of significant amounts of contamination at depth. It is probable that more fractures can be induced at deeper levels if the fracturing equipment design is adjusted.

Conclusions

The results have implications for future pneumatic fracturing design and prediction of remediation timeframes. Our study indicates the following:

- pneumatic fracturing is able to spread fluids in the subsurface primarily via previously hydraulically active and inactive natural fractures.
• The pneumatic fracturing technology is in its present state not considered able to overcome the mass transfer limitations set by diffusion in the low-permeability matrix at depth, and thus, improvements to the technology are required.

• More studies are necessary.

References


