LUC numbers of Flow and Contaminant Transport

Groundwater

Methods Note/

A Large Undisturbed Column Method to Study Flow and Transport in Macropores and Fractured Media

by Peter R. Jørgensen[1,2], Klaus Mosthaf[3,4], and Massimo Rolle[3]

Abstract

Intact soil columns can bridge the gap between field studies and idealized laboratory investigations of flow and transport in macropores and fractured media. However, the value of intact column studies is often hampered by shortcomings such as lack of column intactness, small column size, and column rim flow, which can cause serious artifacts and hamper system understanding. The flexible-wall pressurized large undisturbed column (LUC) method overcomes these limitations and is a valuable approach to analyze fluid flow and solute transport in macroporous and fractured geological formations. The method investigates subsurface processes in complex media, mimicking in situ conditions and facilitating the control of system boundary conditions including effective stress. In recent years, considerable experience has been gained through different applications of the LUC approach. Modeling tools have also been developed for a detailed interpretation of flow and transport processes in LUC systems. This paper describes the steps of the LUC method from column excavation in the field to experimental setup in the laboratory. The description encompasses the key features of the sampling of LUCs in field excavations, the laboratory setup, the procedure for hydraulic and transport experiments, as well as practical challenges and potential issues during operation of an LUC system. Application examples with a fully three-dimensional numerical model of LUC tracer experiments are also presented to illustrate the quantitative interpretation of transport processes in macroporous clayey tills.

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RESEARCH ARTICLE

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Key Points:

- Tracer and pesticide transport experiments in water-saturated large undisturbed columns (LUCs) with visually similar clayey tills showed contrasting behavior
- Interpretation of LUC setups with 3D DFM model including nonequilibrium sorption kinetics based on detailed experimental characterization
- Discrete-fracture-matrix modeling of field conditions using LUC parameters to investigate vertical pesticide migration through surficial clayey till aquitards

Supporting Information:

Supporting Information may be found in the online version of this article.

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Transport of Tracers and Pesticides Through Fractured Clayey Till: Large Undisturbed Column Experiments and Model-Based Interpretation

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Abstract Leaching of contaminants through fractured aquitards such as clayey tills may occur due to typically slow matrix advection and diffusion, or it can be dramatically enhanced in the presence of preferential flow through fractures and macropores. Sorption also plays a crucial role since it can significantly impact contaminant leaching and residence times. These different mass-transfer mechanisms imply a distinct transport behavior and very different time scales for contaminant leaching toward underlying aquifer systems. However, the prevalent controls on contaminant transport and their effects are difficult to assess. This paper shows a detailed characterization of flow and transport processes under water-saturated conditions in two large undisturbed columns (LUCs) collected from two visually similar fractured/macroporous clayey tills typical for the Northern hemisphere. Flow-through tracer and pesticide experiments revealed a contrasting transport behavior. In one column, transport through fractures/macropores was dominant, whereas matrix advection and diffusion had a distinct influence on solute transport in the other column. Detailed 3D discrete-fracture-matrix models were developed to illuminate prevalent controls on contaminant transport and to quantitatively interpret the flow-through experiments with a minimal number of fitting parameters. Nonequilibrium sorption kinetics were included to reproduce the transport behavior of the considered pesticide. The parameters determined from the two LUC experiments were integrated in a vertical cross-section model to investigate the influence of varying fracture properties on vertical solute transport through surficial clayey till aquitards. The analysis showed that small fracture apertures in deeper parts of the aquitard could substantially prolong solute migration times and control solute fluxes.

Presentation of Clayfrac LUC project in Miljøstyrelsen 2019 (Danish EPA)

LUC columns 1.95-3.6 m in Holbæk Site

LUC sampling

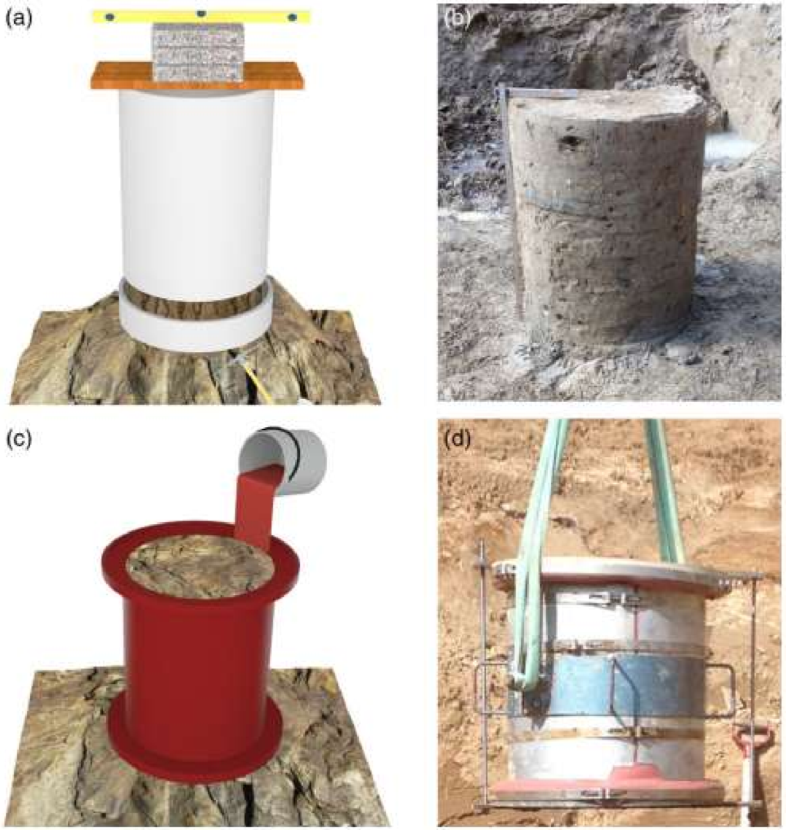


Figure 2. LUC sampling. (a) Cutting shoe and sampling cylinder, which is continuously pressed down vertically by adding weights on top. (b) Final shape of the column, before it is installed within the flexible membrane. (c) Column inside the polyurethane membrane; rim flow is prevented by filling a polyurethane fluid along the column rims. (d) Removal of the column in a split transport cylinder.

(Jørgensen, Mosthaf & Rolle, Groundwater 2019)

LUC column in flexible-wall permeameter under *in situ* soil stress

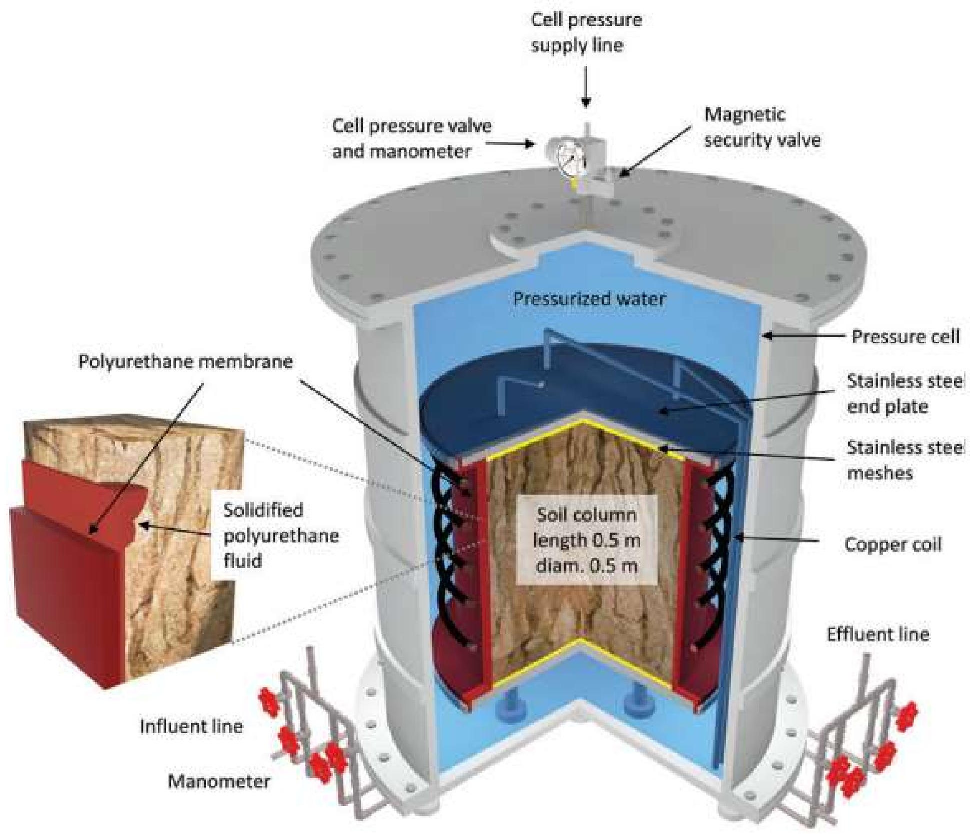


Figure 1. Illustration of the main elements of the LUC setup. The inset shows the prefabricated polyurethane membrane with filled solidified polyurethane preventing flow along the column rim.

(Jørgensen, Mosthaf & Rolle, Groundwater 2019)

Solves rim flow problem of fixed wall columns

Hydraulic conductivity/Darcy´s law

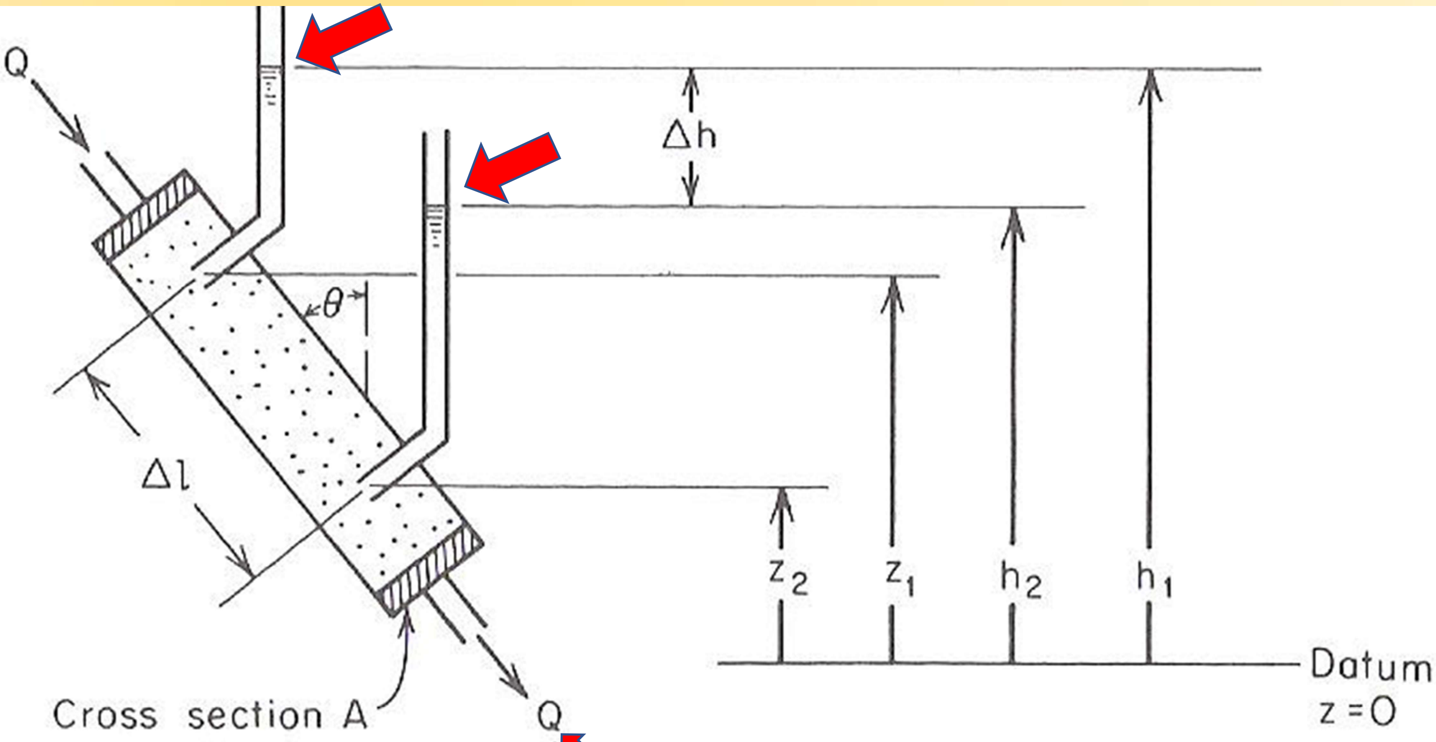
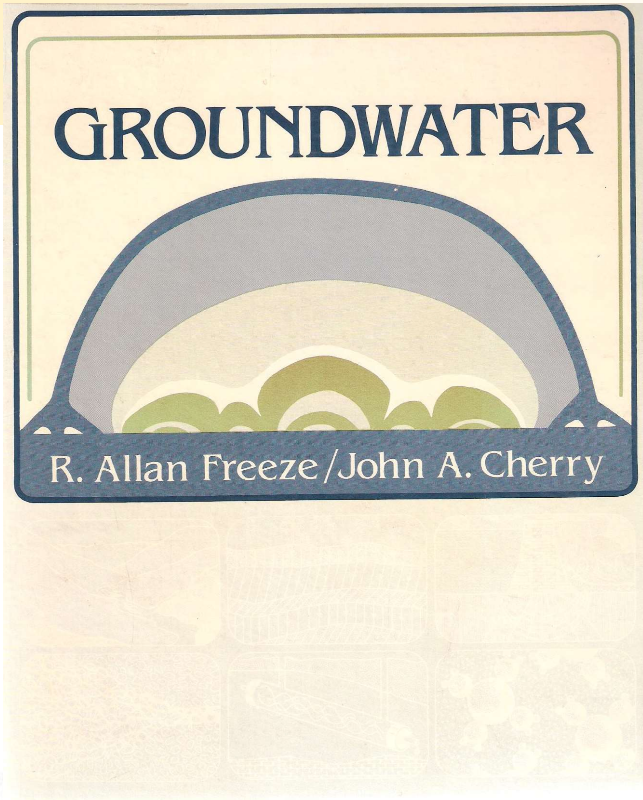
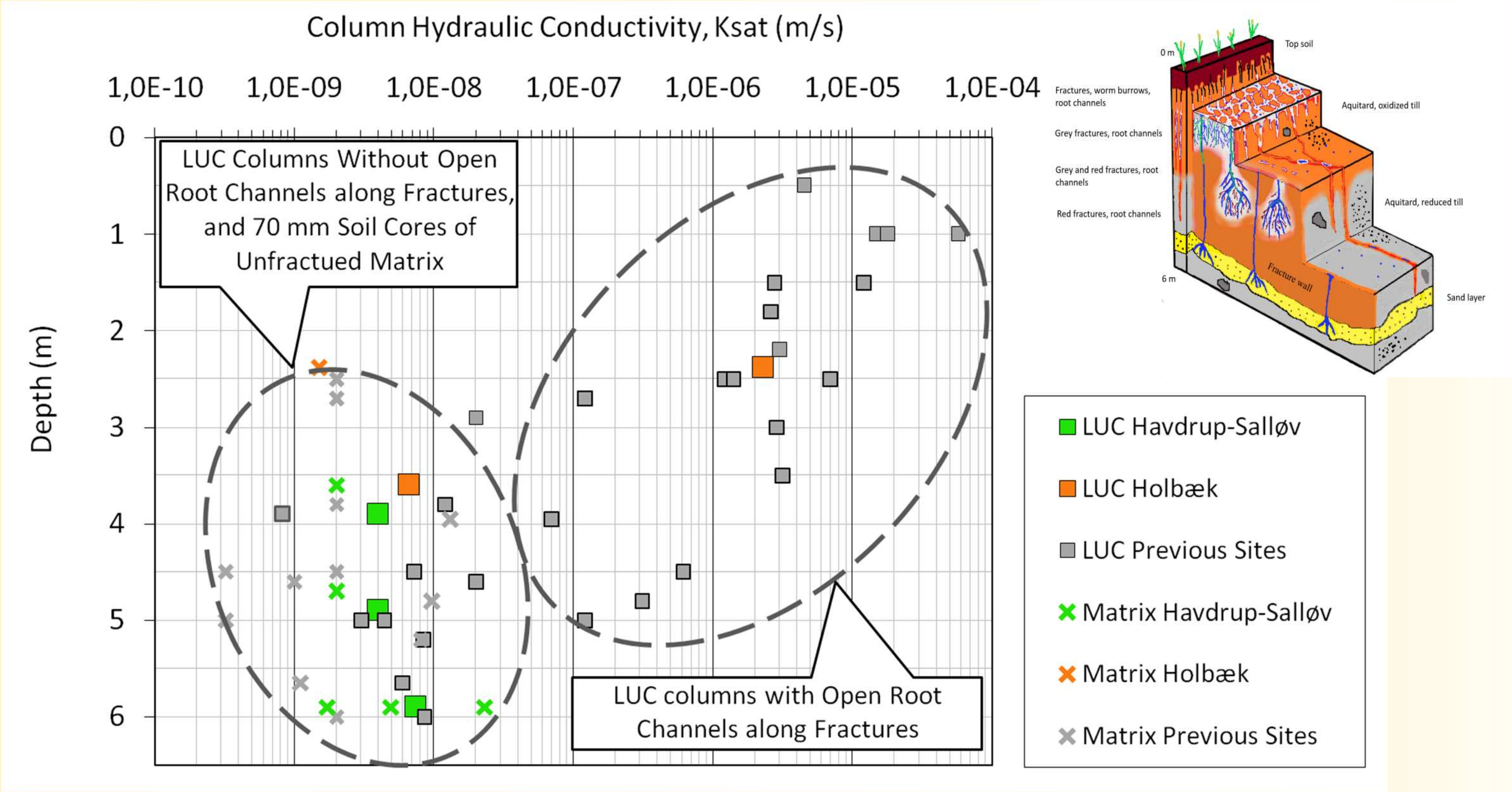


Figure 2.1 Experimental apparatus for the illustration of Darcy's law.

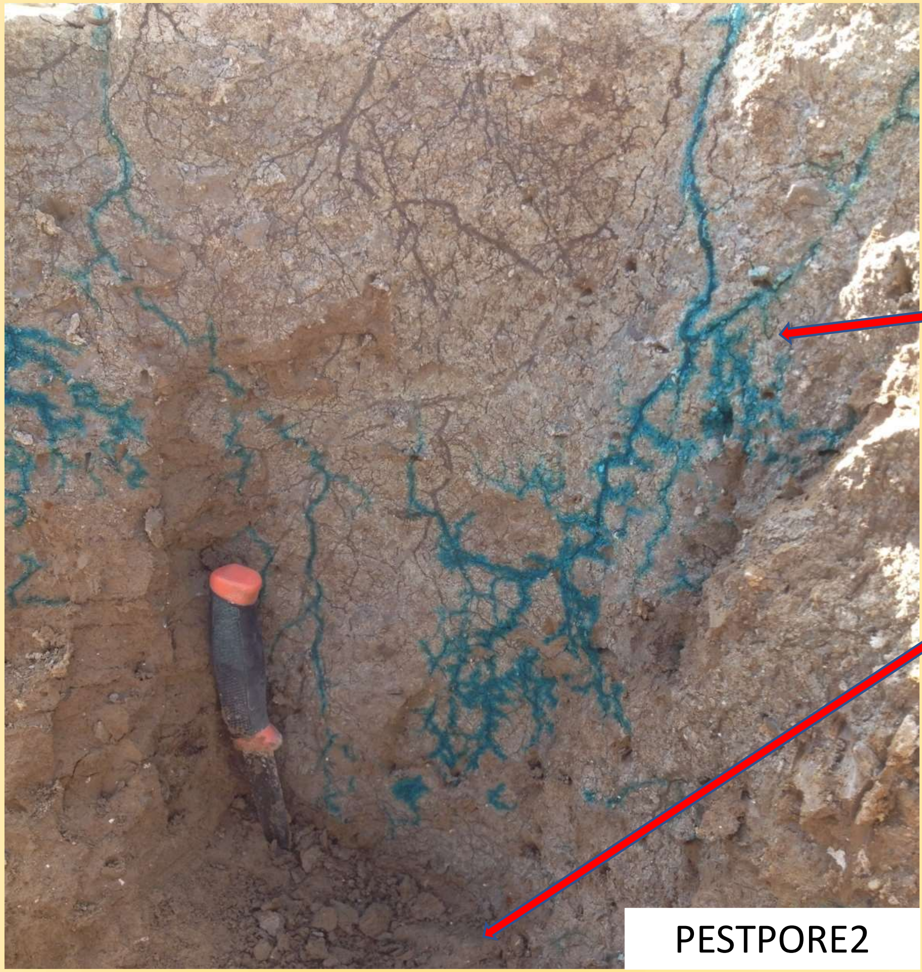
$$Q = -K\frac{dh}{dl}A$$

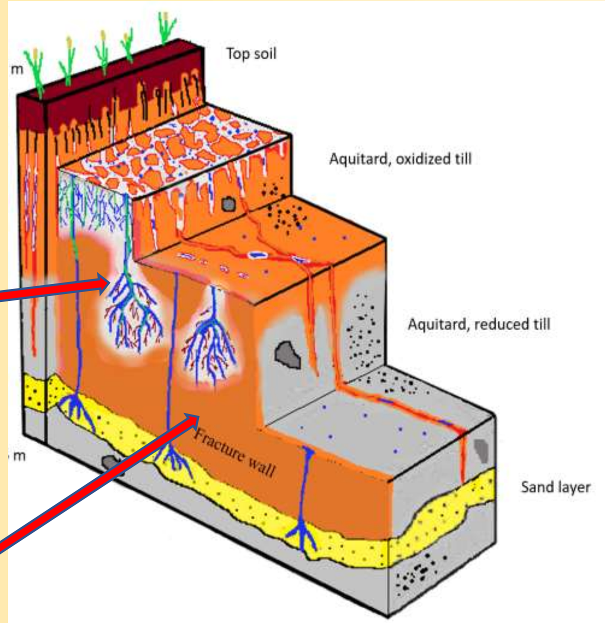


Hydraulic Conductivity from 9 Previous Study Sites



Dyed root channels along grey fractures in 3 m depth





Deep live roots/root channels/cast along fractures in glacial till is well known e.g:

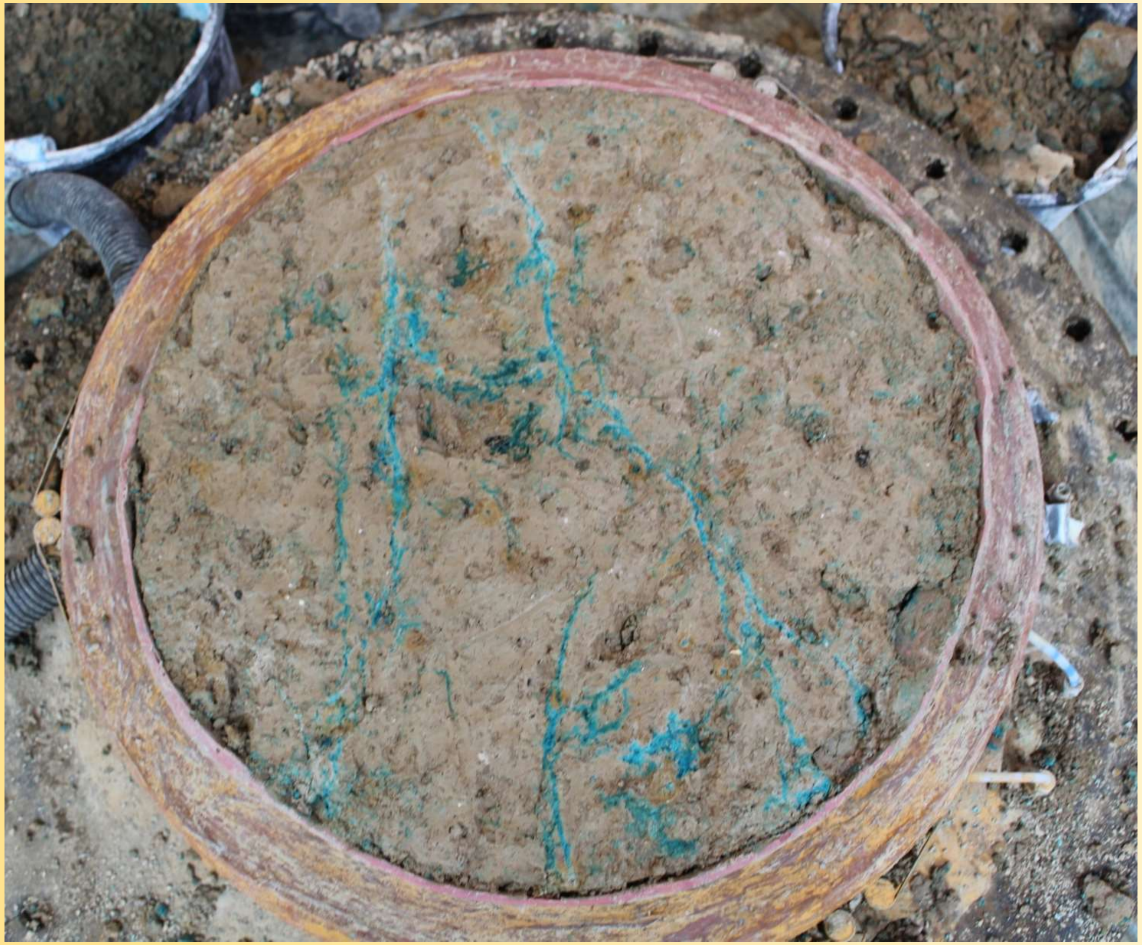
- Jørgensen 1990
- Ruland et al. 1991
- Jørgensen & Fredericia 1992
- Mckay & Fredericia 1995
- Klint & Gravesen 1999
- O´Hara et al. 2000
- Cherry 2012
- Jørgensen et al. 2002, 2004, 2017

LUC3 1.95-2.38 m Holbæk

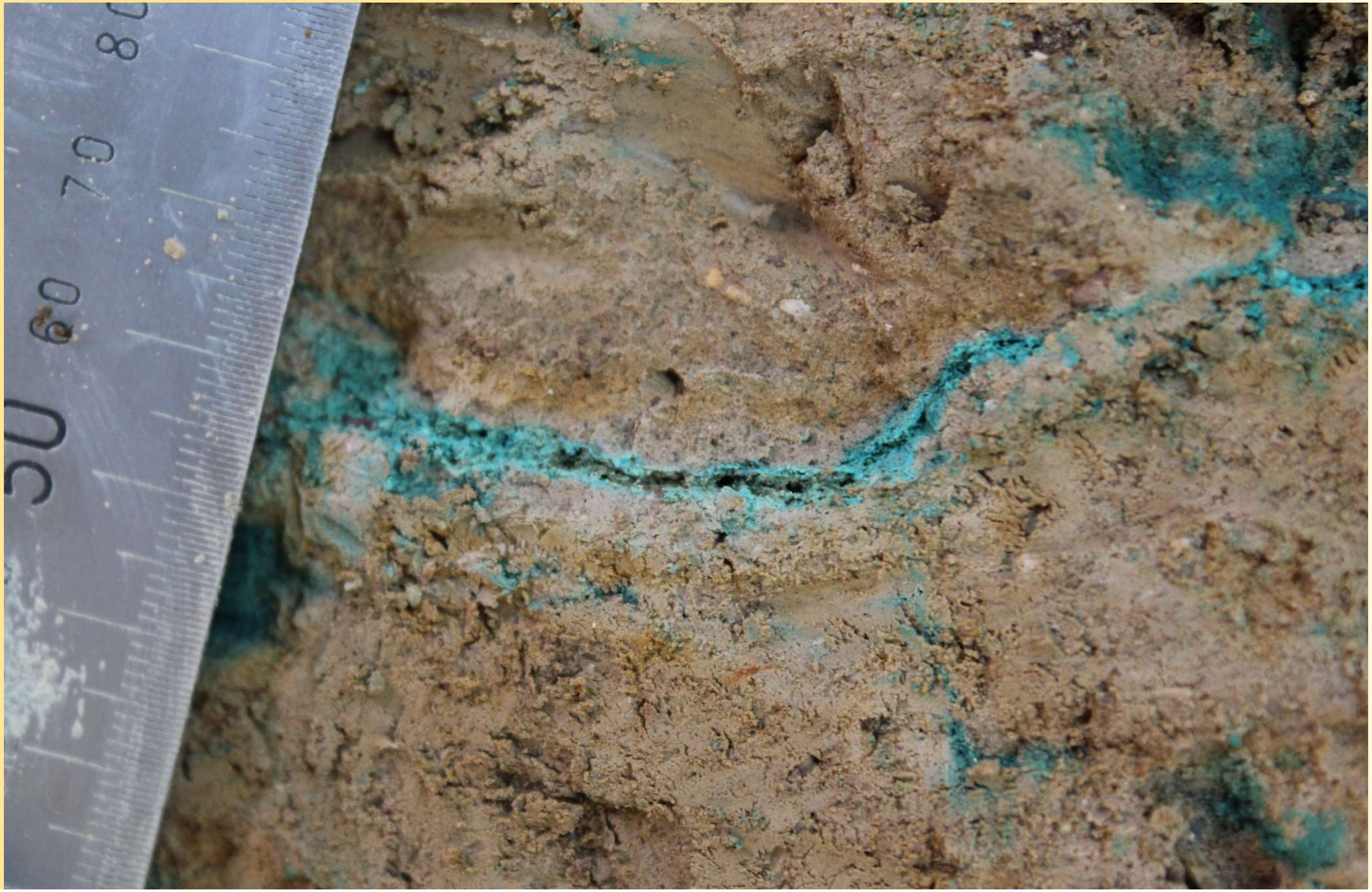
LUC3 1.95-2.38 m Holbæk

Perpendicular to fracture with flattened root remains

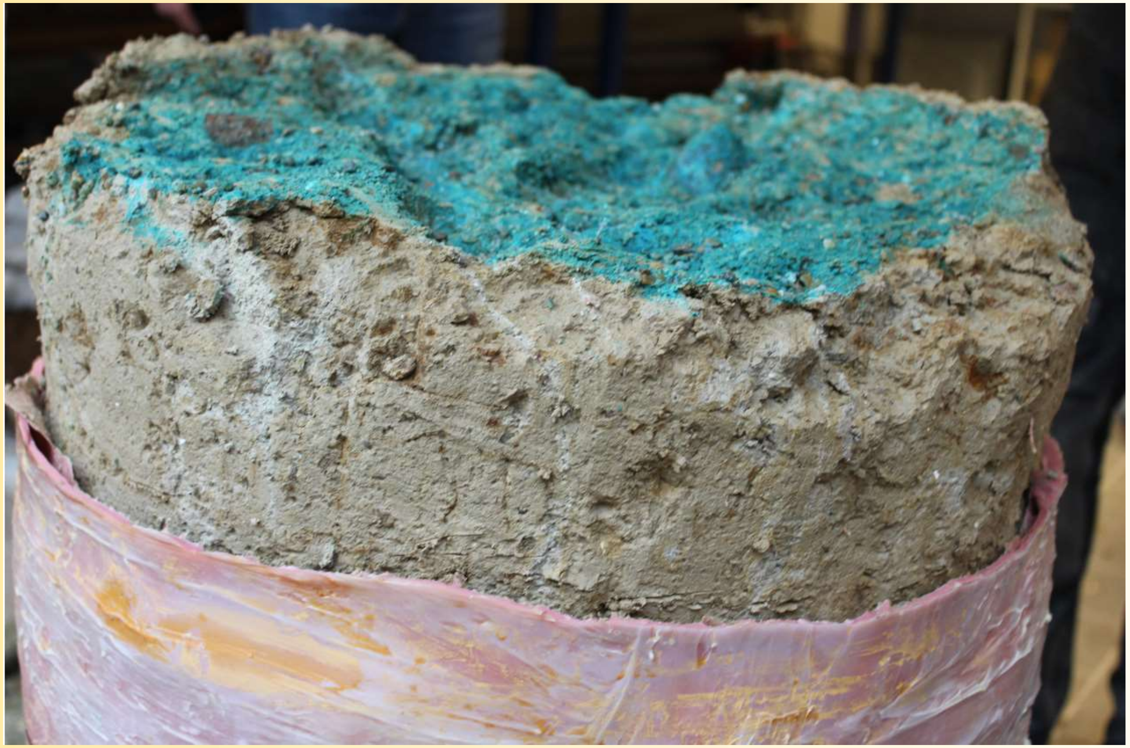
Cutting up LUC after infiltration of dye tracer



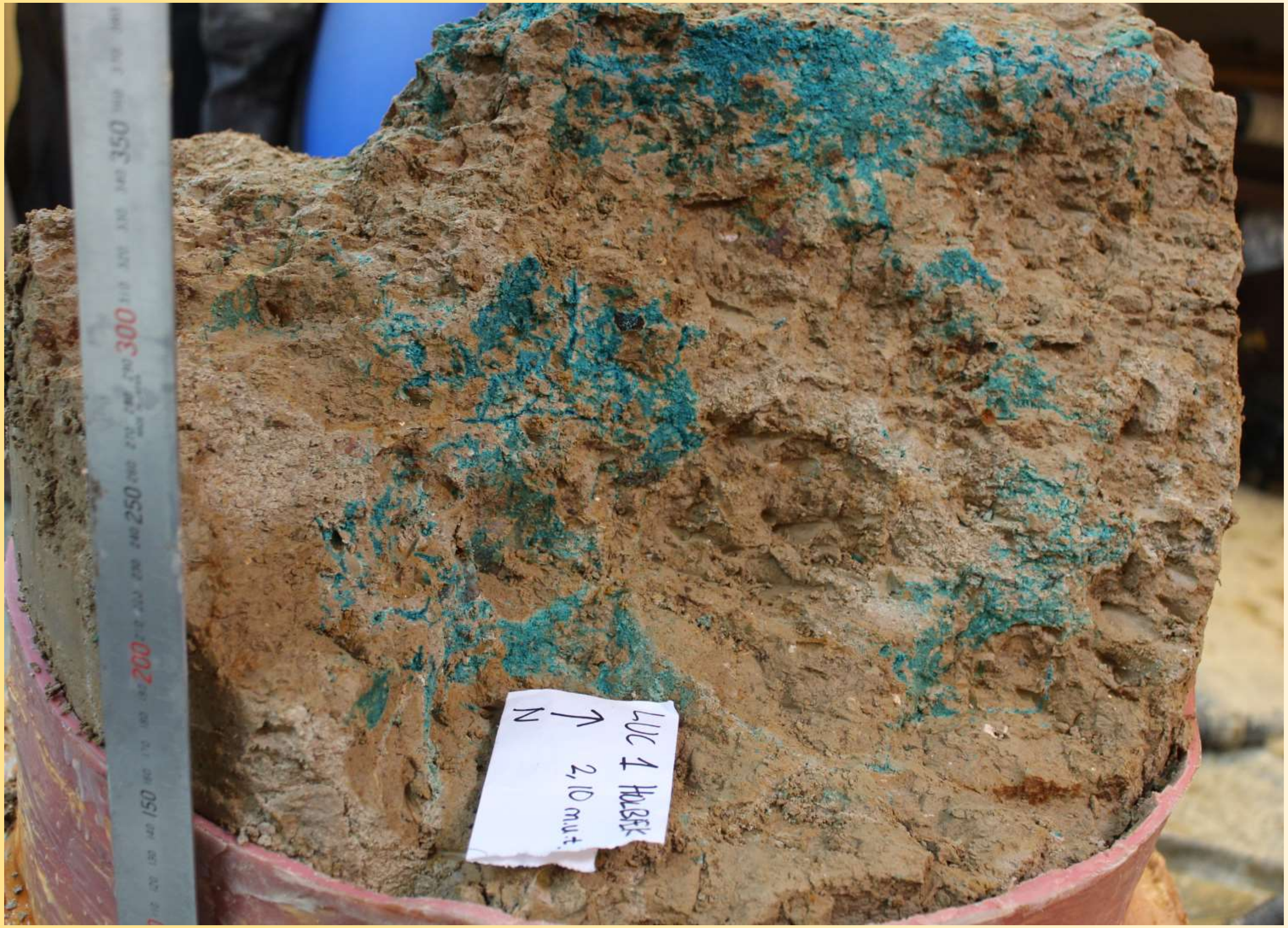
Section perpendicular to fracture with root holes



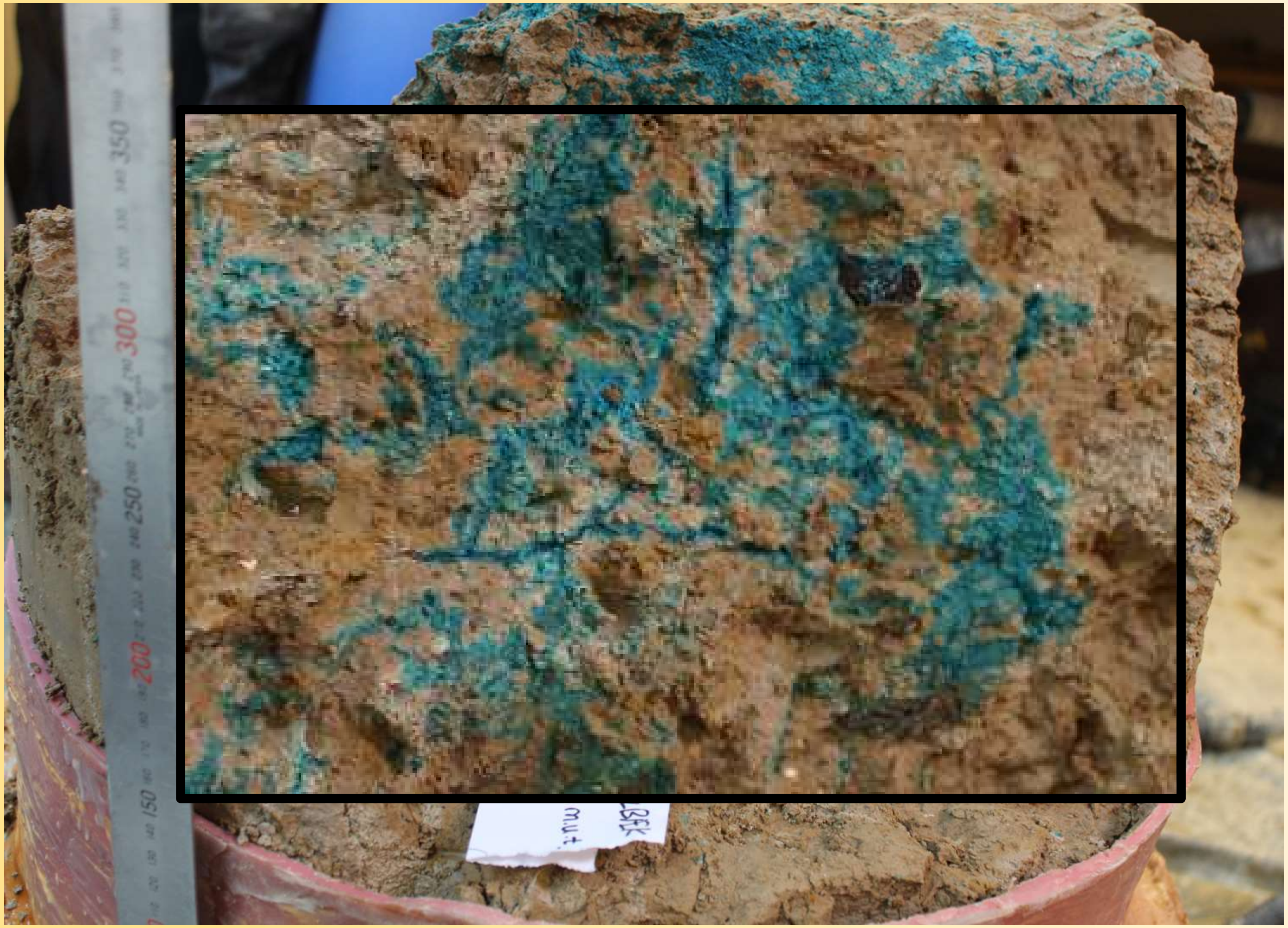
Checking for column rim flow



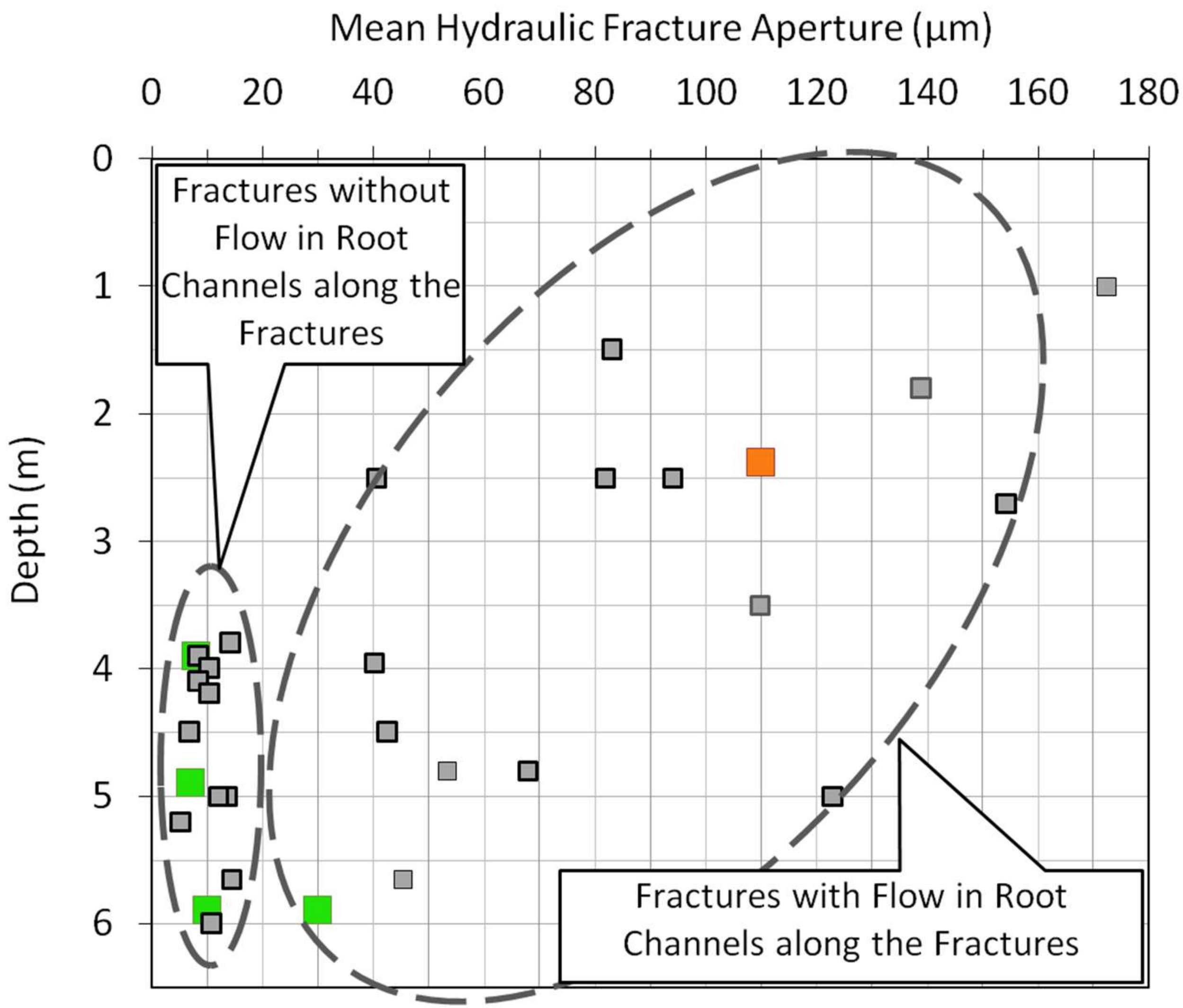
Exposed grey fracture wall surface with dyed root channels

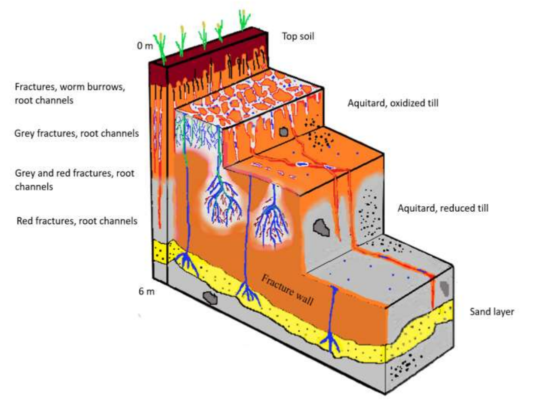


Magnified fracture surface with dyed root channels

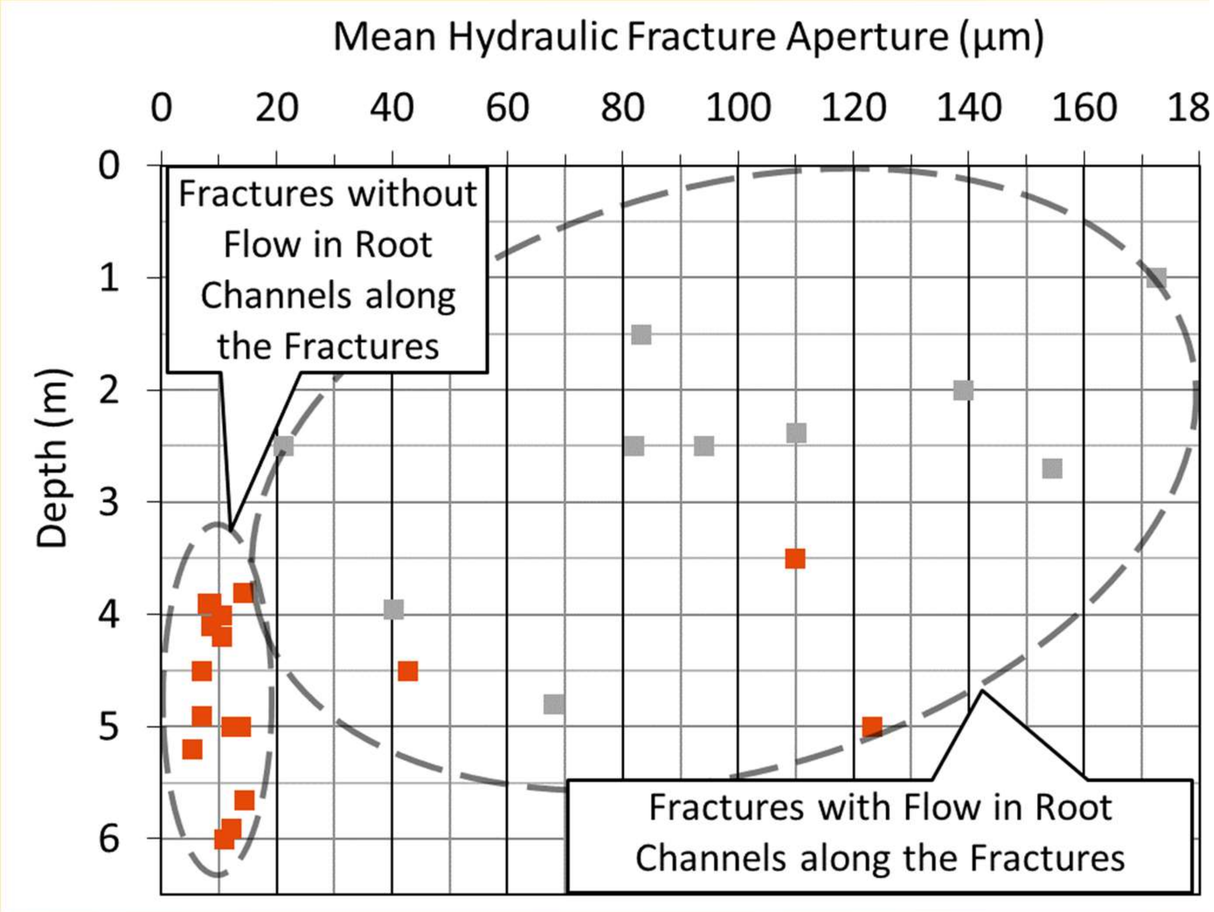


LUC 1992-2019

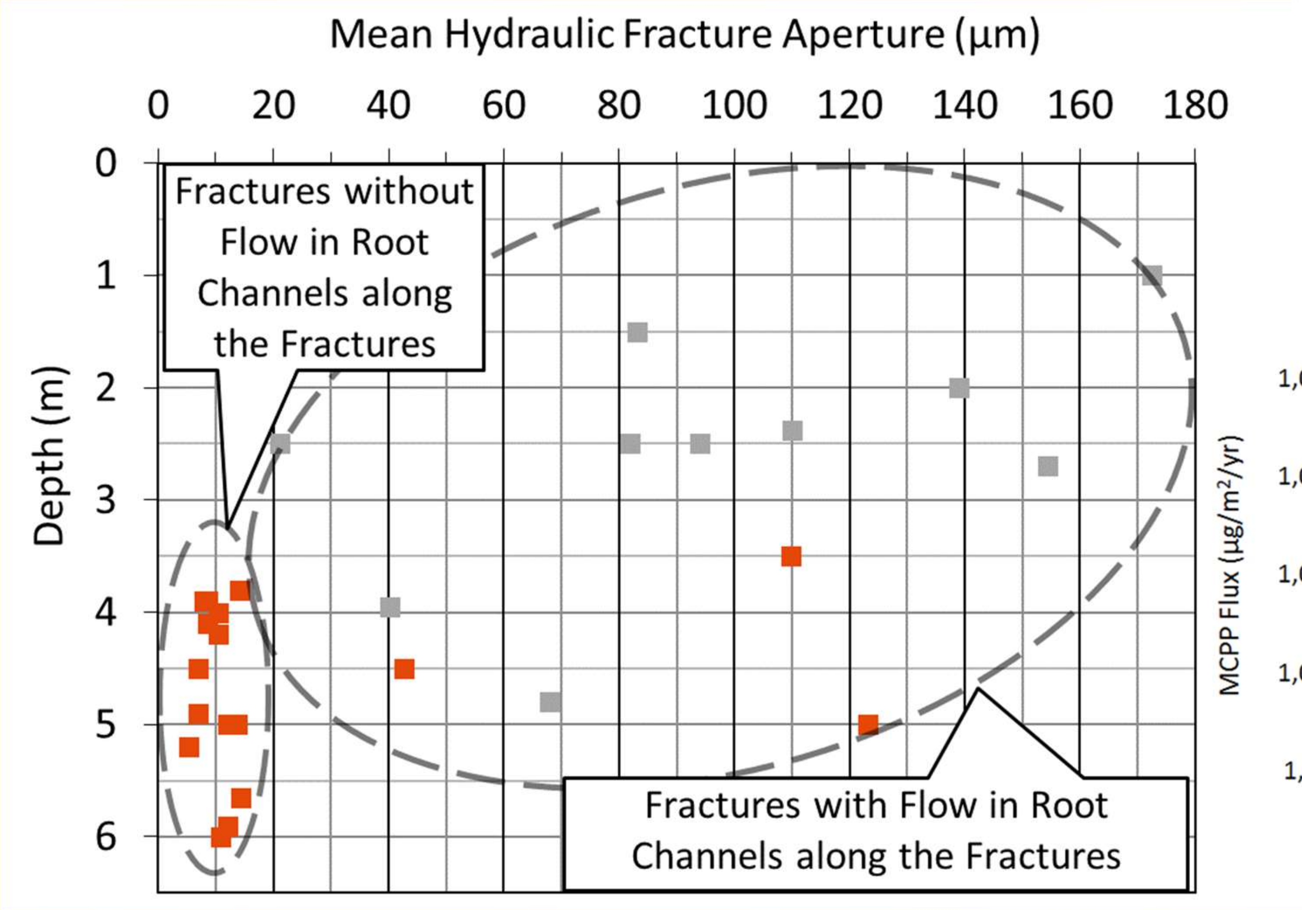


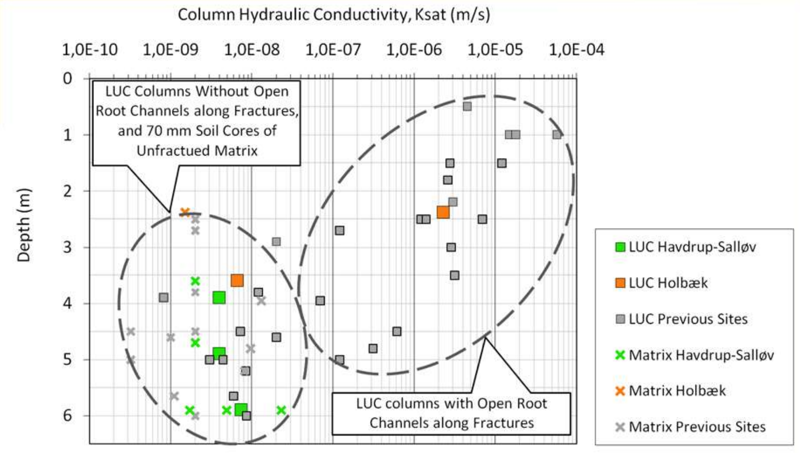


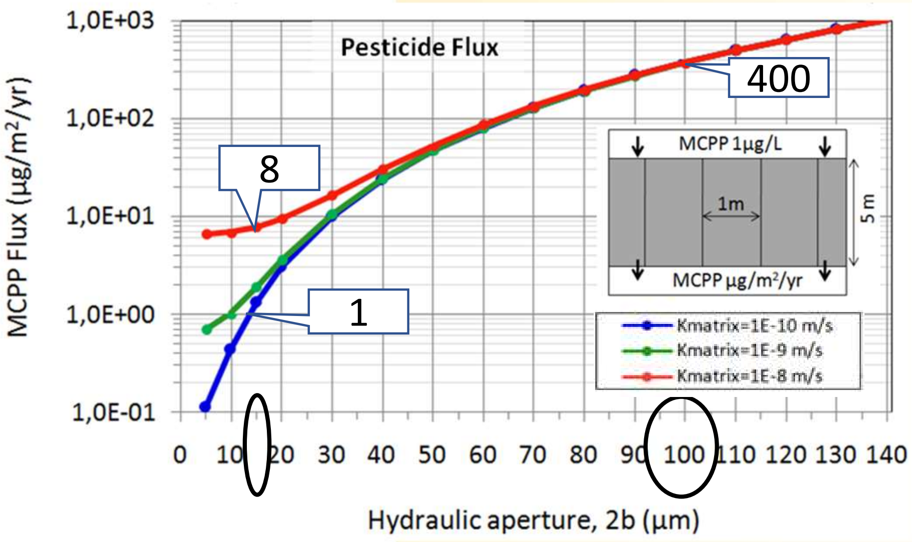
Flow in grey and red fractures



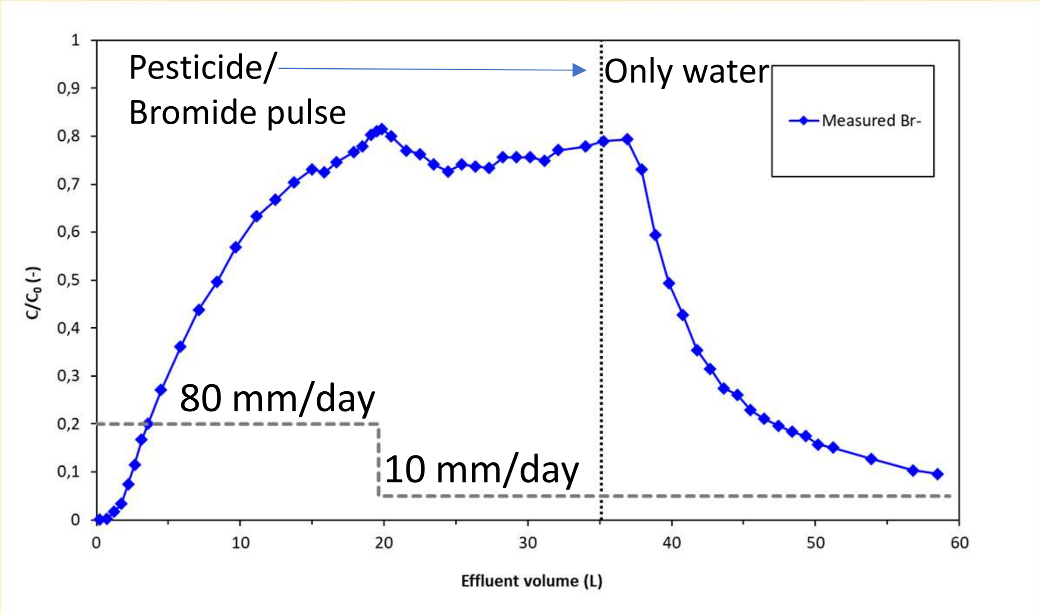
Pesticide flux in grey and red fractures and role of matrix hydraulic conductivity

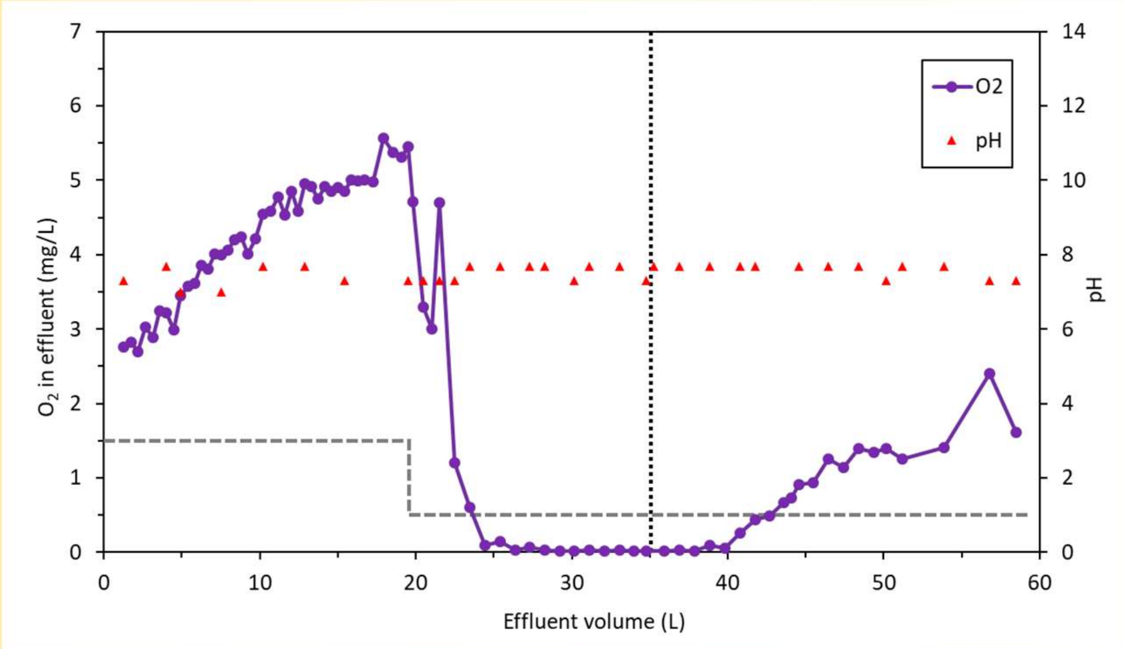






LUC transport experiments; bromide, oxygen and pH in effluent





LUC transport experiments, Pesticides