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Multi-scale mechanistic approach to colloidal transport in porous media

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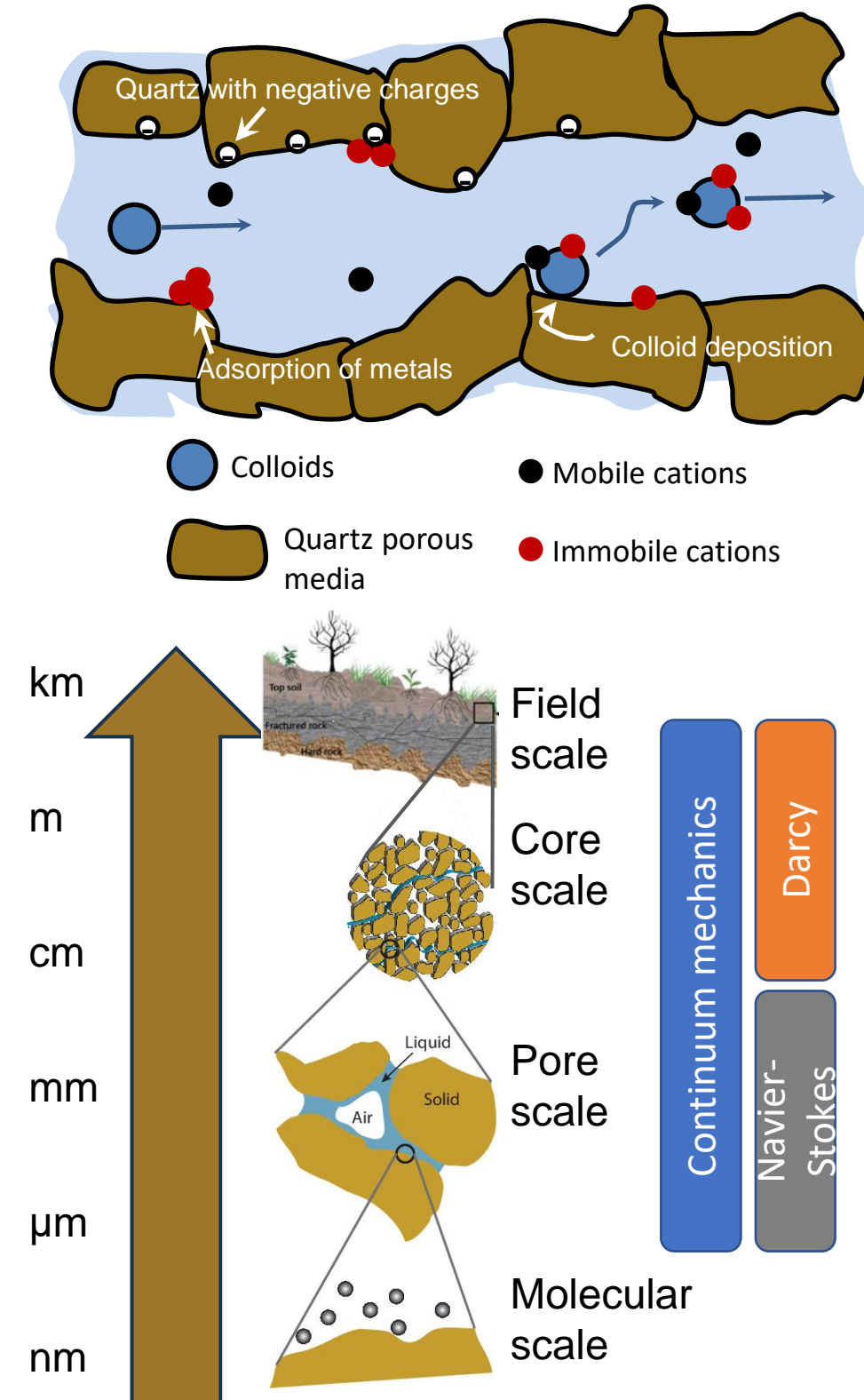
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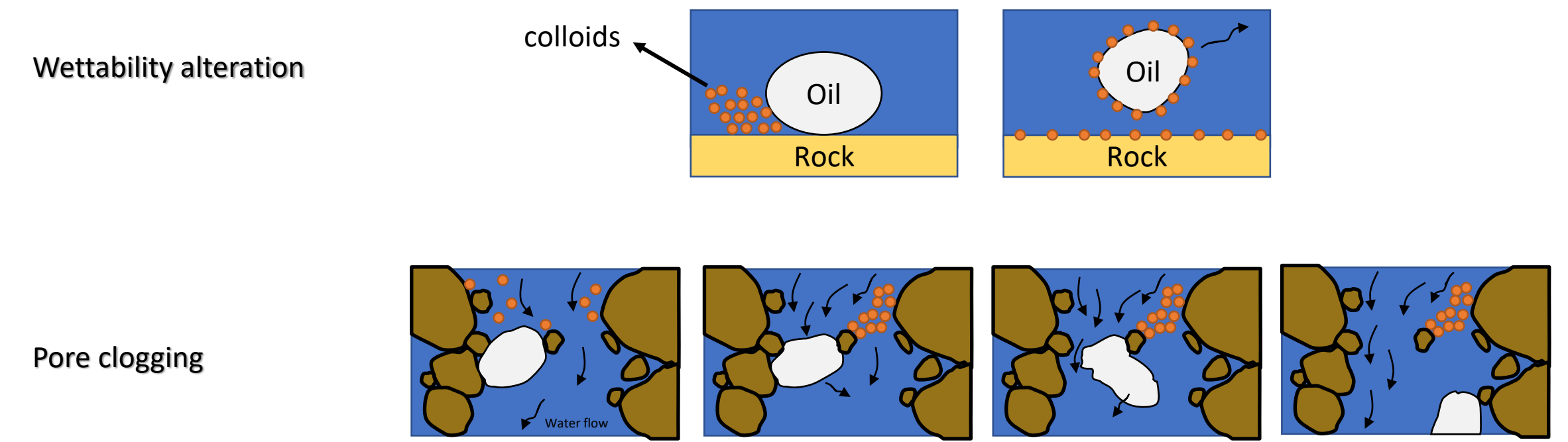
Motivation

- Colloidal particles, including nanoparticles, bacteria, and fine particles, have significant potential to mobilize contaminants in porous media.¹
- Understanding the mechanisms controlling colloidal transport is limited, hindering their effective use in underground engineering, such as groundwater remediation and enhanced oil recovery.
- Therefore, a multi-scale approach combining laboratory experiments and numerical modeling is necessary to accurately predict retention and transport of colloids in porous matrices.



On-going research / perspectives

Prediction of colloidal transport is not only dependent on scales but also on hydro-electro-chemical effects in geological porous media.



4D X-ray micro computed tomography

Time-resolved 3D non-invasive, non-destructive high resolution imaging technique which can be applied in-situ to observe colloid retention and transport processes directly inside the pore matrix.

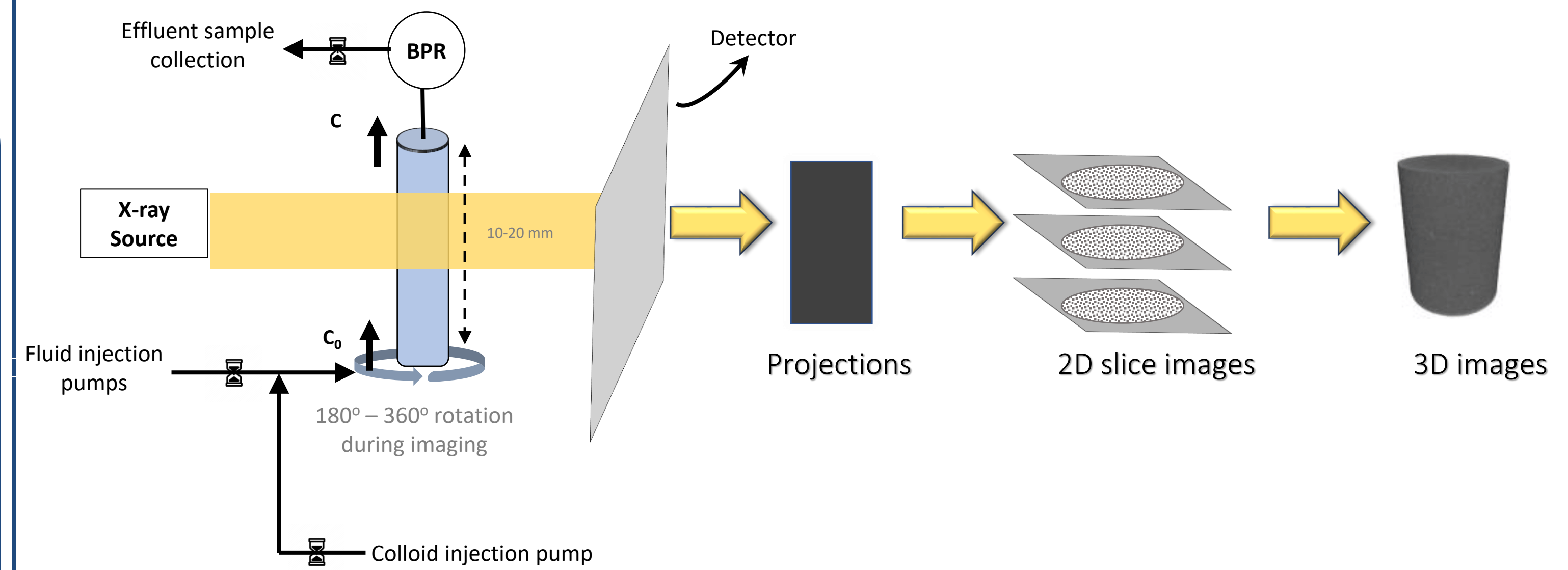
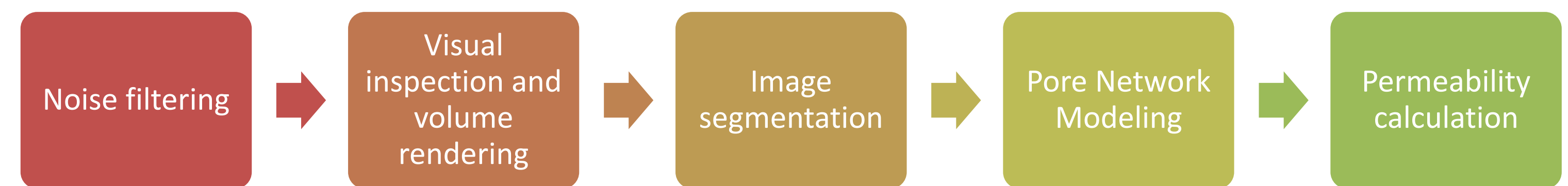


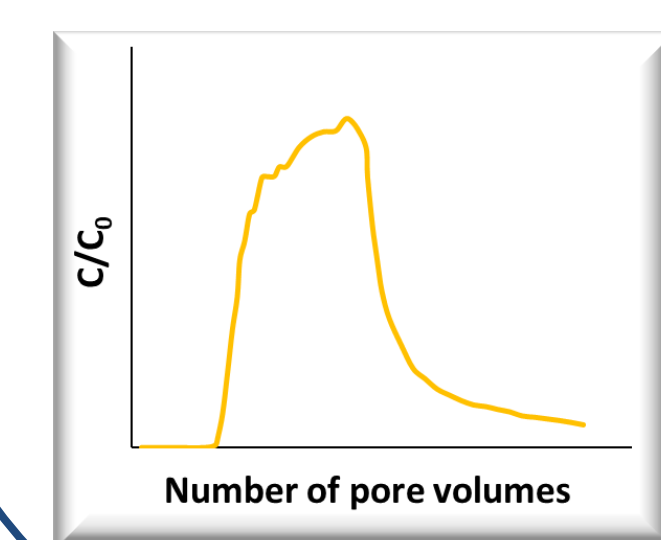
Image processing



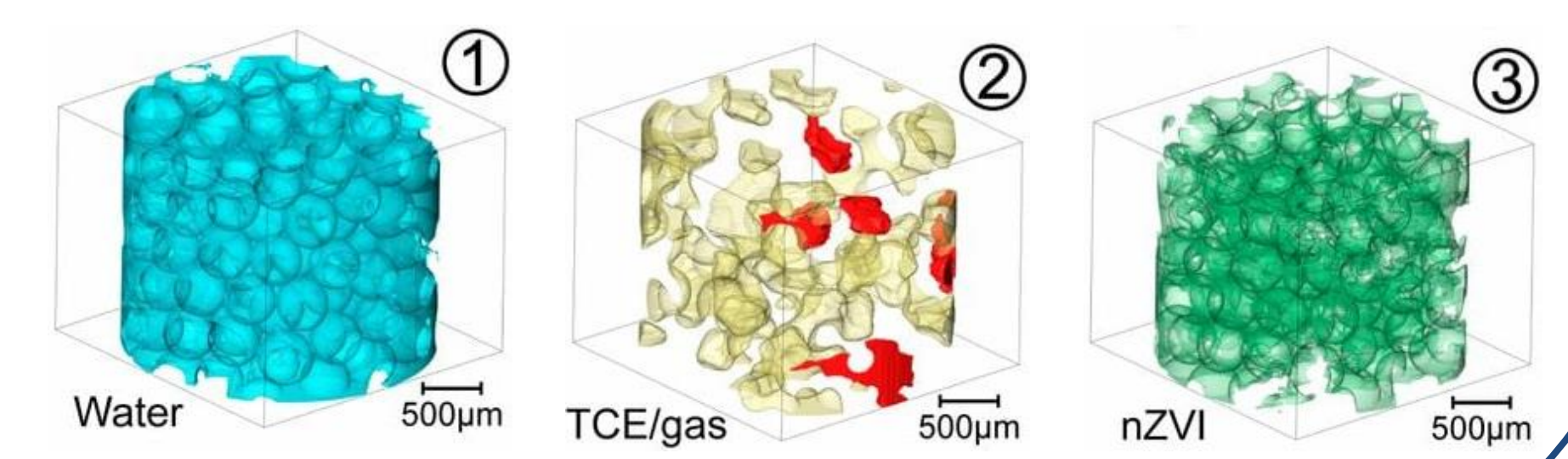
Goals to achieve

- Providing reference dataset validating continuum-scale models.
- Identification of key parameters controlling the distribution of colloids and the subsequent remobilization of fluids using 4D X-ray micro computed tomography.
- Understanding of dynamic processes → Pore clogging, wettability alteration and remobilization of fluids and particles (e.g. snap-off and Haines jump events).

Colloid breakthrough curves



Fluid / colloid redistribution



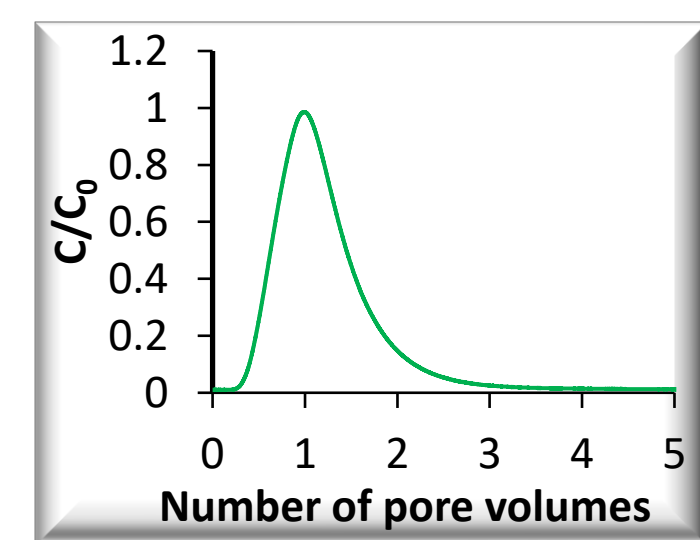
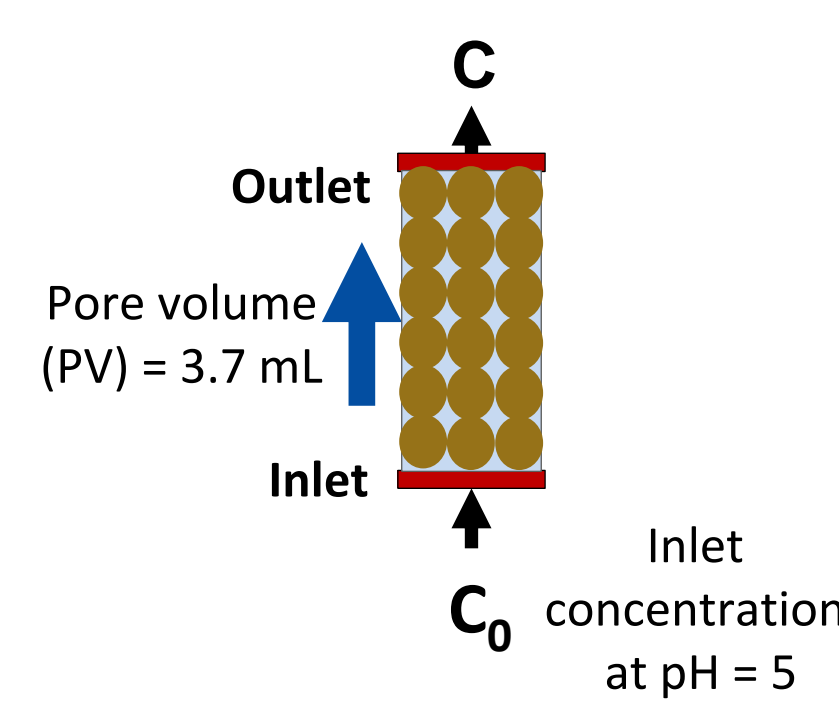
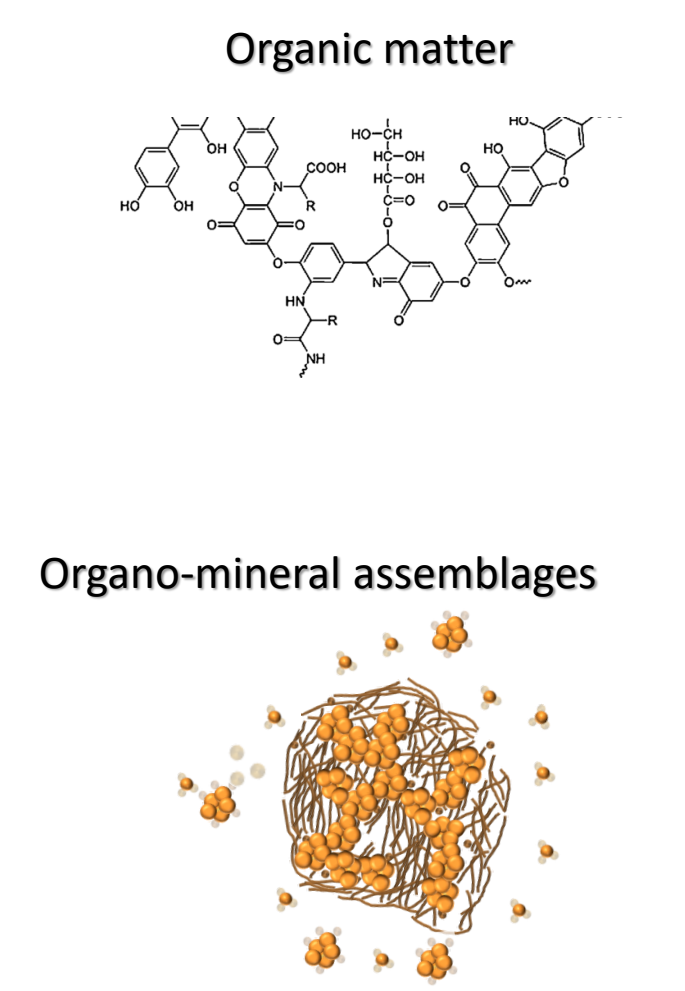
Pak et al. (2020)⁴

Summary

- Colloids play a crucial role in mobilizing contaminants in subsurface systems.
- REE are emerging contaminants used in many modern-day technologies.
- Breakthrough curves show enhanced REE mobility in the presence of colloids.
- Limited knowledge on the mechanisms controlling colloid retention and transport hinders their widespread use in underground engineering, such as groundwater remediation and enhanced oil recovery. Therefore, a combined modeling-laboratory approach focused on multi-scale phenomena is necessary.

Role of colloids in contaminant transport

- Rare Earth Elements (REE), now recognized as emerging contaminants are shown to have strong interactions with natural colloids (Fe/Mn/Al (oxyhydr)oxides, and humic substances).²
- Limited knowledge is available on the impact of C- and Fe-rich colloids on REE mobility in subsurface systems under flow-through conditions.



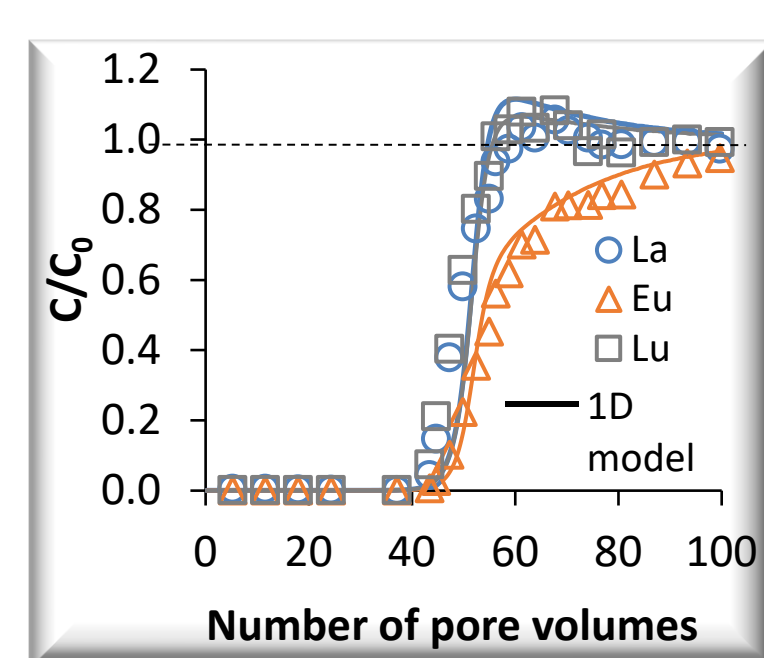
Breakthrough curve (BTC) of conservative tracer

Experimental design

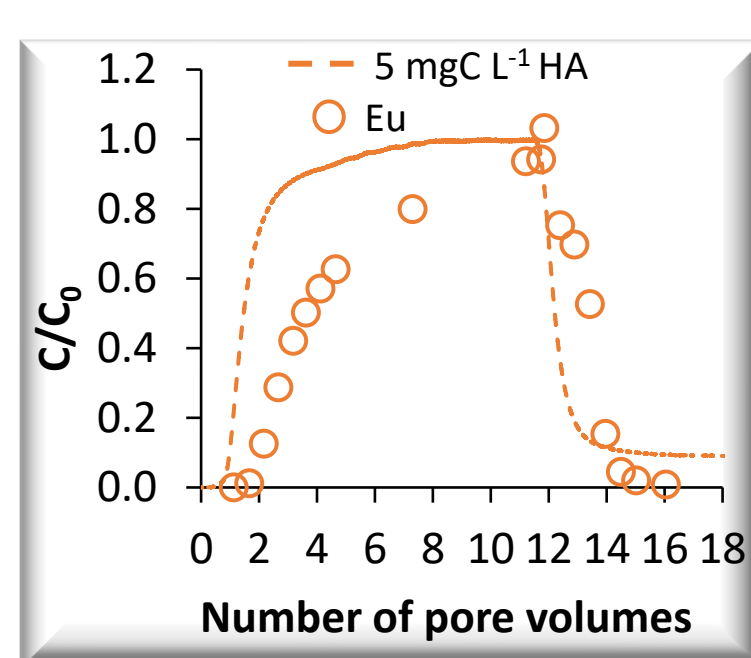
- The sorption of REE under flow-through conditions was investigated using a liquid chromatography system (Äkta™ Pure) equipped with a fraction collector (F9-R).
- A constant total metal ion concentration (C_0) of $0.7 \mu\text{M}$ was injected through fixed-bed columns packed with quartz sand. Colloids were injected until a complete breakthrough of HA was achieved.
- The height of the porous bed was approximately 5 cm, the flow in the column was from bottom to top at a fixed rate of 0.5 mL min^{-1} , using 5 mM NaCl solution at pH 5.
- The dissolved metal ions concentrations from the column outflow solutions (C) were measured using Triple Quadrupole ICP-MS.

Results

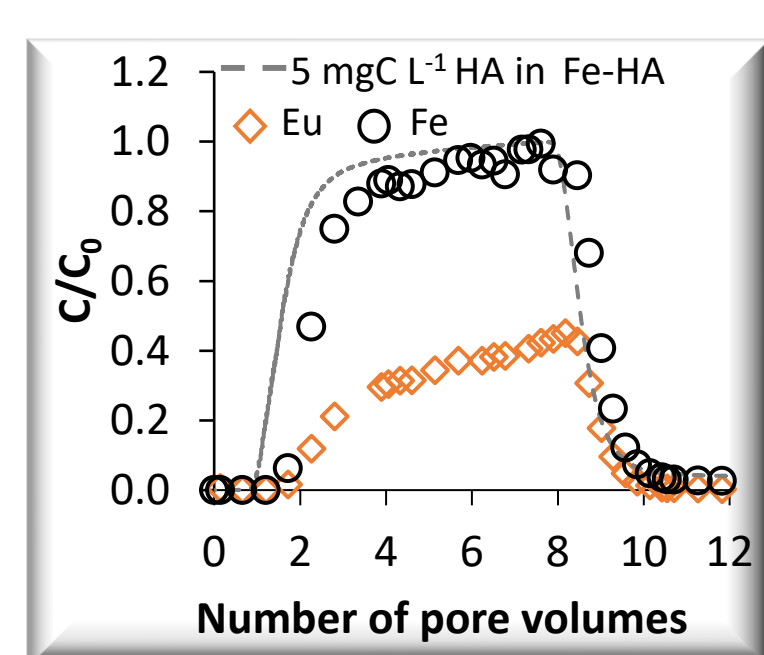
- In the absence of colloids, no breakthrough of REE was observed until 40 PV showing that REE are strongly adsorbed to the quartz.
- 1D reactive transport model developed in Phreeqc for aqueous REE transport accurately describes the experimental breakthrough curves.³
- Colloids represented the dominant transport pathway for REE which otherwise would have remained immobile in the quartz column.
- Variability in REE patterns is an important tool to probe competitive adsorption in the context of transport from water to soils in porous media.



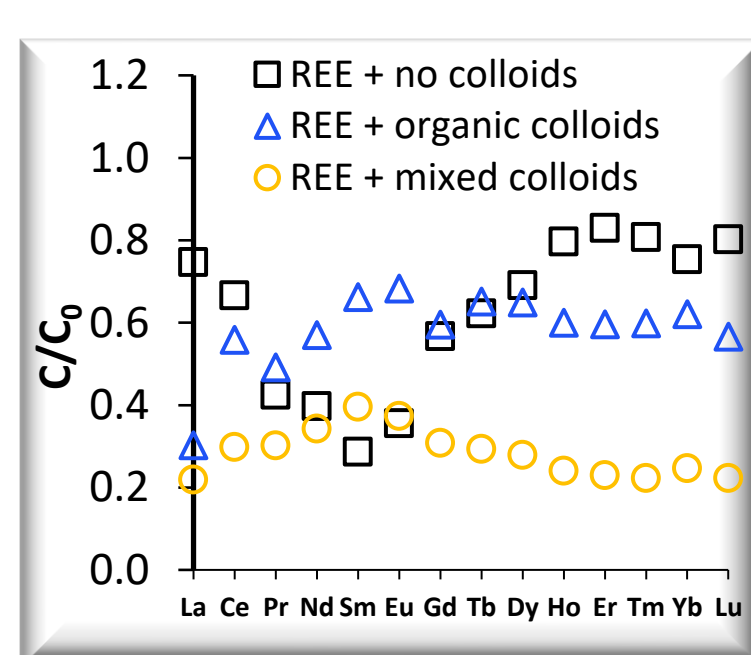
REE aqueous transport



REE with organic colloids



REE with mixed colloids



REE patterns in the column

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