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Which role do preferential flowpaths and fractures play in the subsurface reactivity in heterogeneous aquifers?

Camille Bouchez, Nicolas Lavenant, Julien Farasin, Thierry Labasque, Ivan Osorio, Julien Bouchez, Francesco Gomez, Laurent Longuevergne, and Tanguy Le Borgne
Geosciences Rennes, CNRS, Université Rennes 1, France (camille.bouchez@univ-rennes1.fr)

The underground fracture pattern, which results from tectonic, climatic and biological stresses, drives water storage dynamic and nutrient cycling in the deep critical zone. Despite a gradual decrease of fracture density with depth, the fracture network is strongly heterogeneous and anisotropic, resulting in a complex pathway distribution with variable hydraulic conductivities. High celerities occurring in preferential flowpaths govern the dynamic response of discharge flows to extreme recharge events. However, the role of preferential flowpaths in transporting fresh meteoritic water and biota remains poorly studied, while the delivery of meteoritic reactants is crucial to initiate underground chemical reactions.

Here, we study a fractured aquifer in a crystalline catchment located in Brittany (Guidel, France) to investigate the link between depth, water transit time and subsurface reactivity in fractures. Oxygen is used as a tracer of fresh water inputs because its availability has a tremendous impact on oxidation-driven reactions such as weathering processes and microbial activity. We performed vertically sampling of fracture fluid with an inflatable packer capable of isolating fractures in an artesian well located in the discharge chemically-reduced zone of the aquifer. Major ions, dissolved reactive gases, dissolved anthropogenic gases, stable isotopes (O, Sr and Si) and microbial diversity were analysed on five fracture waters sampled at depth between 20 and 55 m. Significant differences have been observed between fractures and younger and more oxygenated waters were found intermittently in fractures at 47 and 54m, with dissolved oxygen concentrations ranging between 0.1 and 0.5 mg/L. The penetration of oxygen in deep fractures reveals either a rapid transport of oxygen or a low consumption of oxygen in preferential flowpaths. These hypotheses are tested with a Discrete Fracture Network model, where first-order reaction rates have been implemented, and the temporal dynamic of oxygen is assessed and linked to water transit time in fractures. We investigate the concept of transit time and water-rock contact time and discuss the relevance of mean transit time to evaluate subsurface reactivity.

Preferential flowpaths thus not only make fractured aquifers more dynamic but can also, under extreme recharge conditions, efficiently transport fresh water at high depth. The advective-dominant transport of oxygen through artery-like fractures could have a significant impact on short term microbial activity and the associated nutrient cycling but also on long term weathering front propagation.