Reactive transport modelling in porous fractured media: contribution to the understanding of weathering processes

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Résumé

Weathering processes are involved with many of the current challenges of the geoscience community such as climate regulation, the critical zone formation and the supergene deposits formation of highly demanded metals (e.g., Co, Ni, Sc, U). Yet, understanding the different processes controlling the weathering remains a major challenge. Recent studies have highlighted fractures' critical impact in controlling the dissolution and redistribution processes by creating preferential fluid flow pathways. However, the impact of physical and chemical heterogeneities on the weathering front progression is still not totally understood.
Due to the complexity of the mechanisms involved in the weathering, reactive transport models (RTMs) are a powerful tool to understand, quantify and predict the coupling effect of chemical and physical processes at different scales and across large temporal scales on weathering. The study of the Ni heterogeneous distribution in New Caledonia is an excellent case study to shed light on the impact of fractures on the formation of weathering heterogeneities. In New Caledonia, indeed, Ni-laterite supergene deposits result from the weathering of the peridotite by the downward progression of rainwater. The dissolution/precipitation process leads to the progressive enrichment in Ni at the interface between the saprolite and the oxide horizon. Therefore Ni distribution can be used as a proxy of the weathering front progression

In this study, we investigate the impact of fracture networks as chemical and hydrological heterogeneities on the weathering front migration in fractured rock mass through different models of increasing complexity. First, the weathering of an unfractured peridotite column, is compared with the weathering of a fractured peridotite rock mass modelled by a dual porosity formulation (D.P. Model). The two different geochemical fractures and matrix sub-domains, corresponding to the different characteristic times of processes at stake, are coupled with an exchange term, which controls the diffusive exchange of the solutes. These mass transfer functions, however, cannot fully capture the complex flow behaviour in fractured media, and the application to reactive transfer processes is also delicate. In addition, a discrete fracture matrix model (DFM model) is built to study the impact of the fracture connectivity on the weathering. The DFM model divide the domain into regions for which an explicit fracture formulation is coupled with a continuum representation of the matrix, adding more resolution to the description, albeit at the cost of heavier numeric simulations.

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The effect of the connectivity of the fracture network on the redistribution of metals of interest is thus studied, and potential hotspots of interest are identified. The results are discussed considering field observations from Ni-laterite deposits in New Caledonia.
Reactive transport models successfully recreate geochemical heterogeneities observed in the field. They originate from the physico-chemical differentiation of the fractured rock mass into interconnected sub-domains. The fractured bedrock acts as a kind of filtering mechanism for the newly formed phyllosilicates: Ni phyllosilicates precipitate more likely in fractures, while Mg phyllosilicates remain trapped in the matrix because of the differences in residence time and liquid-to-solid ratio. The DFN modelling allows to go deeper in the understanding of the impact of a complex fracture network on the weathering front progression. Depending on its geometry and permeability, the fracture network controls the fluid flow, hence favouring the formation of geometrical weathering heterogeneities.