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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Dissolution and precipitation of fractures in soluble rock" *by* Georg Kaufmann et al.

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Reply to interactive comment by *Anonymous Referee #1*

We would like to thank the Anonymous Referee #1 for his valuable comments and take the opportunity to discuss the points made.

General comments

The motivation for the study outlined in the Introduction relies mostly on previous work of the authors and ignores the large amount of work over the last 15 years aimed at better understanding permeability changes in fractured rock caused by fluid-mineral reactions. A sub-sample of other studies are cited in the Processes section, but each is briefly addressed independently with no effort to synthesize the results and findings of these previous studies to offer a compelling motivation for the current study. The

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statement that the previous studies focused on small-scale processes and the current study focuses on large-scale behavior is a bit of a generalization and not exactly true (e.g., Hanna and Rajaram, 1998; Chaudhuri et al., 2008; Szymczak and Ladd, 2011 each consider scaling issues associated with related reaction processes).
We will move the review of selected work on fracture evolution to the introduction, group them into laboratory studies and numerical studies, and summarise their main outcomes as a motivation for our work. We note that the literature review is aimed to put our specific work into a broader context.

This manuscript would be more compelling if it started with a more nuanced discussion of the motivation for the study in light of the significant number of related studies in the recent literature. Some of the details of the model are not well justified or documented, which undermines the impact of the simulation results. For example, the decision to represent fractures as a single, one-dimensional tube is not supported by recent experimental, numerical, and theoretical results (see for example references cited in the previous paragraph), which show the importance of the two- or three-dimensional flow field within fractures on the development of preferential flow paths by dissolution. Here, you essentially assume that, at time zero, a preferential flow path exists across the entire domain and it then grows by dissolution. It may be reasonable to ignore the development stage of these preferential flow paths, but the onus is on you to explain why in the context of other papers that focus on this interesting process. See other modeling issues in my detailed comments below.
Our decision to use a single conduit to show dissolution and precipitation in a fracture for different soluble rock types is based on the assumption that the three aspects we choose to discuss with our work are best discussed in a simple setup. While we admit that reality is much more complicated, we would like to focus on the effect of chemical kinetics and rock type on the fracture evolution, keeping 2- and 3D-effects from fracture network out of the scope.

Detailed comments

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p.4 lines 19-21: This example doesn't seem relevant. My understanding is that the uplift resulted from over-pressurized fluids, not from mineral precipitation.
The referee is correct, we will drop this example.

p. 5 eq.1: Doesn't seem necessary to define Ql and Qt because your expression for Qt is also valid for laminar flow when the friction factor is defined as 64/Re (e.g., eq. 3).
We redefine flow to a single non-linear equation.

p. 8 lines 5-6: This needs more discussion. It is true that mass transport across the diameter will reduce value of the effective reaction-rate coefficient, the amount of reduction depends on the fluid velocity, diffusion coefficient, and reaction rate (e.g., Szymczak and Ladd, 2011). Furthermore, when the flow transitions to turbulence, mass transport is no longer limited by diffusion, but turbulent mixing.
The modeling of calcium flux is a well established field, which has been well documented during the past. We add references to guide the reader to the relevant discussion.

p. 8 lines 10-13: This deserves a reference.
References will be added.

p. 9 lines 1-2: Why simplify to assume a hydrostatic pressure distribution when the model implicitly calculates the pressure loss along the flow conduit? Calculating the actual pressures seems trivially easy.
Due to the extent of the deeper models the hydrostatic pressure dominates, and hydraulic pressure is smaller. We will discuss our choice in the text now.

p. 9 lines 13-14: How is the flow rate in each fracture element calculated? Presumably this involves solving a system of linear / nonlinear equations depending on the flow rate. More information on the details of these calculations would be helpful.
We will add references to clarify our modeling approach.

p. 9 lines 15-16: This must also include eq. 5 for the mass flux between each cell?

Link to equation will be added.

p.9 lines 10-18: The scheme described here is first-order in both space and time and, thus, likely quite sensitive to ΔT and Δx. Did you conduct a sensitivity analysis to ensure that ΔT and Δx were adequately small to achieve convergence?
We discretise the fracture with concentration increments, thus use the change in concentration to determine the length of each sub-element in the fracture. Time steps are chosen small enough to ensure convergence. We explain our choice of spatial and temporal discretisation in more detail in the text.

p. 10 line 7: What is a 'classical fracture'?
A classical fracture in the literature is a fracture enlarged by dissolution and experiencing a breakthrough event. The reason is the positive feedback between flow and dissolution. Will be explained in the text.

p.10 line 27: Why increase the tube diameter for the deeper fracture? As noted by Kaufmann et al. (2014) and many others, fracture permeability is expected to decrease with depth. It would seem more physically relevant to include a tube with the same diameter at the surface and decreasing with depth than a larger fixed-diameter tube.
The referee is correct, fracture width in general diminishes with depth. However, our reasoning to use a larger initial diameter for this case is mentioned in the text, we want to obtain a similar breakthrough time for a better comparison to the water-table model discussed earlier.

p. 12 line 25: Can you give an example when one might expect to have such a supersaturated influent solution?
We will add an example.

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