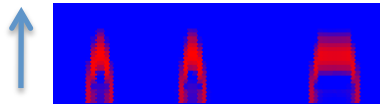


Fluid mixing and mineralization – the role of stable and traveling reactive zones

Daniel Koehn¹, Gary Mullen^{1,2,3}, Adrian Boyce³, Ulrich Kelka⁴, Renaud Toussaint⁵

1: Geozentrum Nordbayern, University of Erlangen/Nuremberg, Germany, daniel.koehn@fau.de, 2: University of Glasgow, UK, 3: SUERC, East Kilbride, UK, 4: CSIRO, Deep Earth Imaging, Kensington, Australia, 5: Institut de Physique du Globe de Strasbourg, Université de Strasbourg/ITES, France



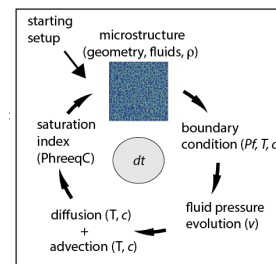
How can faults mineralize without clogging?

Traveling mixing waves and stable mixing waves

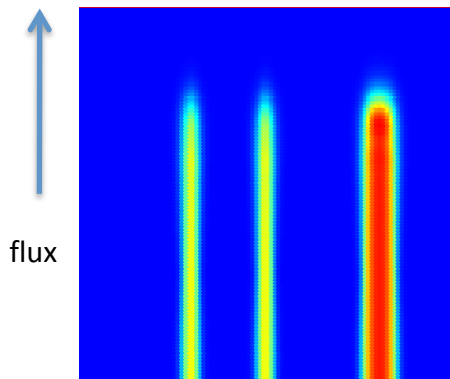
Fluid mixing is an important ore-forming processes for hydrothermal mineralization. When upwelling and pore fluids mix, the conditions for ore-precipitation are met. We investigate the case of two fluids, a pore fluid derived from seawater and a hot metal-rich fluid that enters the system at high fluid overpressure. The mineralization is reflected by changes in the saturation states of respective mineral phases.

Model

Merging Elle and PhreeqC, solve pressure field and derive fluid velocity, solve advection and diffusion for T and several c, calculate fluid properties for every node and get saturation indices for minerals.

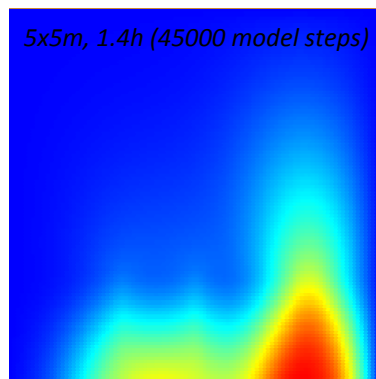


Advection dominated



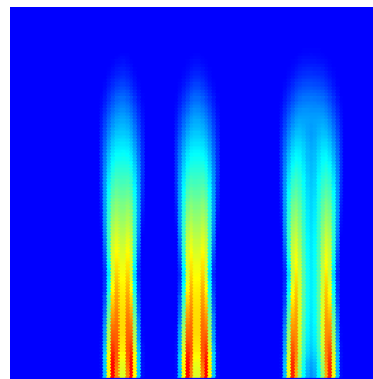
Concentration of incoming fluid

Diffusion dominated

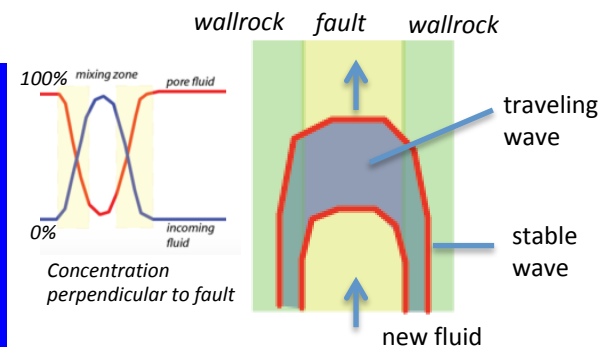


Temperature due to incoming fluid

Mixing (mainly dif)



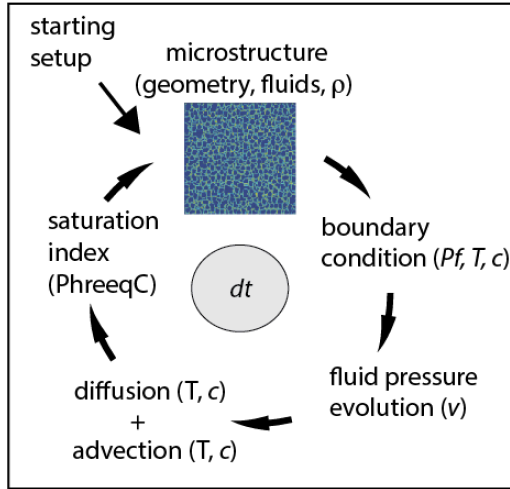
Accumulated saturation index Barite



New fluid pushes pore fluid away. Mixing zone in fault moves with fluid. Mixing zone at the fault walls is stable – potential mineralization zone (25cm).

ELLE: Bons, P.D., Koehn, D., Jessell, M.W., 2008. Microdynamics Simulation. Springer Lecture Series in Earth Sciences, pp. 406.

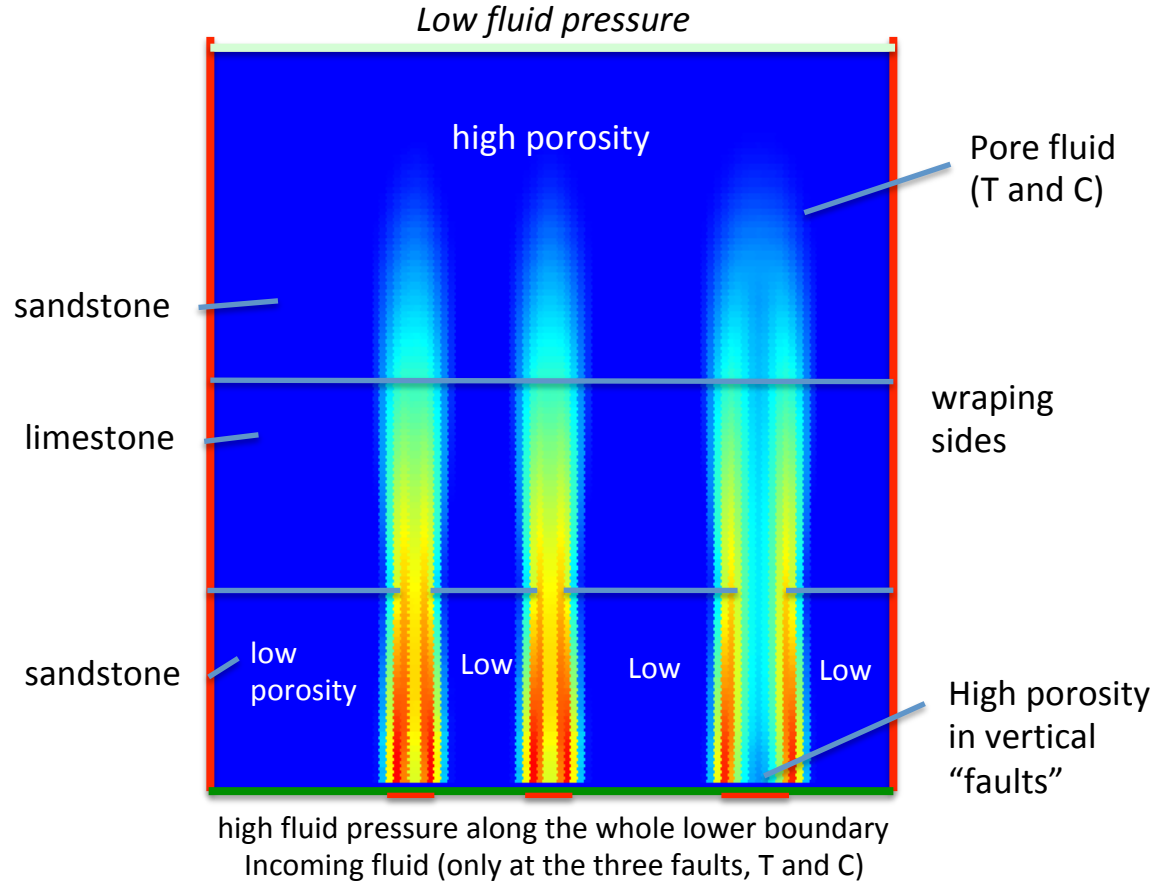
PhreeqC: Parkhurst, D.L., and Appelo, C.A.J., 2013, Description of input and examples for PHREEQC version 3--A computer program for speciation, batch-reaction, one- dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 pp, <http://pubs.usgs.gov/tm/06/a43/>.



- Solve pressure field
- Get fluid velocity
- Solve advection (T, c)
- Solve diffusion (T, c)
- Feed info at every node into PhreeqC
- Determine fluid composition and saturation indices for different minerals at every point.

Model setup

Flux of a metal rich fluid along three vertical permeable faults into a porous limestone layer with a seawater derived pore fluid. Mixing of the two fluids leads to high saturation indices for barite.



PhreeqC

Pore fluid:

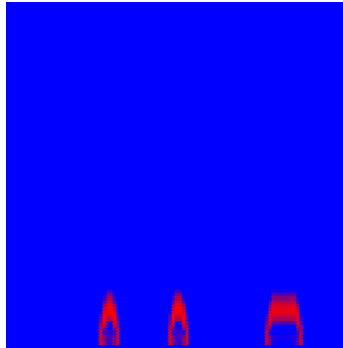
pH 8.22, T 25 degrees C, Alkalinity 141.682, Ca 412.3 ppm, C(4) 0.0 ppm, Mg 1291.8 ppm, Na 10768 ppm, K 399.1 ppm, Si 4.28, Cl 19353 ppm, S(6) 2712 ppm

Incoming fluid:

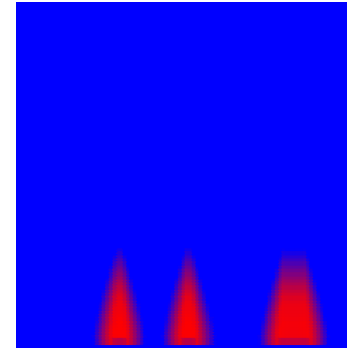
pH 5.37, T 90 degrees C, Alkalinity 146, Na 57200 ppm, K 1000 ppm, Mg 2310 ppm, Ca 31700 ppm, Ba 39 ppm, Si 30 ppm, Cl 158000 ppm, S(6) 68 ppm as SO₄, Fe 261 ppm, Mn 83.5 ppm, Pb 34.6 ppm, Zn 172 ppm.

Ph: In the simulation we add inorganic carbon during the equilibration with calcite. The alkalinity is defined as HCO_3 for both the pore fluid and the infiltrating fluid.

Advection/diffusion of T
and
 HCO_3 , C(4), Ca, Mg, Na, K, Si, Cl,
S(6), Ba, Fe, Mn, Pb, Zn



Mixing (Barite)



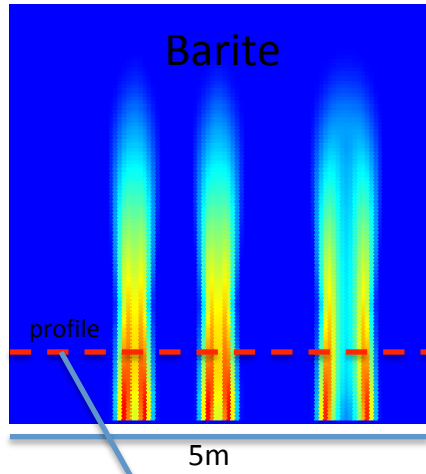
Incoming fluid (Goethite)



Examples for saturation indices that develop during the mixing of these two fluids is given below:

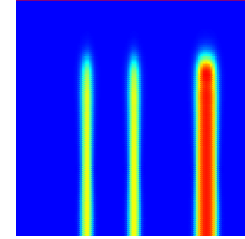
Anhydrite 0.40 CaSO_4 , Aragonite 0.31 CaCO_3 , **Barite 0.66 BaSO_4** , Calcite 0.43 CaCO_3 , Chalcedony 0.58 SiO_2 , Dolomite 0.50 $\text{CaMg}(\text{CO}_3)_2$, $\text{Fe}(\text{OH})_3(a)$ 0.80 $\text{Fe}(\text{OH})_3$, Goethite 8.23 FeOOH , Gypsum 0.11 $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, Hematite 18.74 Fe_2O_3 , Jarosite-K 2.06 $\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$, Quartz 0.88 SiO_2 , Talc 5.25 $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$

Results

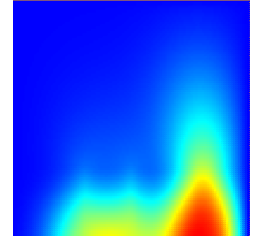


The faults act as conduits for the incoming fluid. The flux is fast with the incoming fluid almost crossing the model (5m) within 1.4 hours (0.001m/s). Diffusion is dispersing the concentration such that the smaller faults lose concentration whereas the larger fault retains its concentration. In the walls the diffusion length scale of elements is in the range of 25cm. Fluids mix a little bit by advection because fluid is added to the system. However, most of the pore fluid is pushed away by the incoming fluid. The main mixing in this model takes place by diffusion. Hence diffusion defines the length scale for the mineralization of the fault walls.

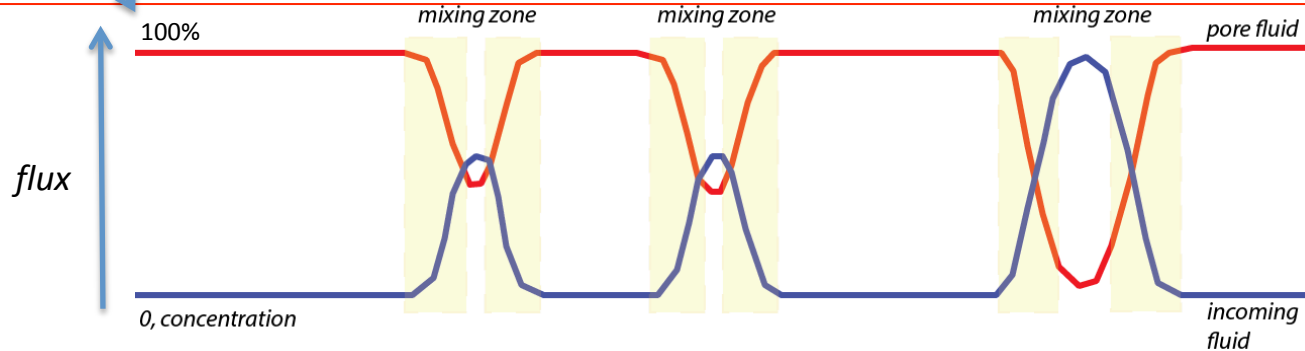
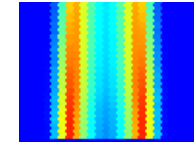
Concentration
incoming fluid



Temperature
field



The diffusion length scale of elements versus temperature is very different. T -diffusion is much faster stopping the advection when too much T is lost to the host-rock.

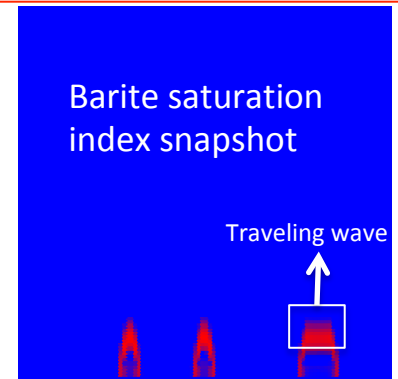
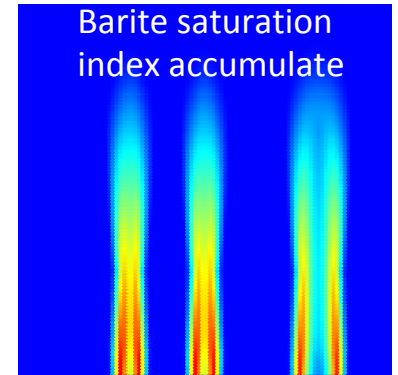


Barite saturation Index accumulated over time showing that index in the walls is highest

The mineralization wave at the front of the incoming fluid is traveling with the incoming fluid and is dispersed a bit by diffusion. The positive saturation index in this zone is spatially not stable but moves with the fluid. Hence during the mineralization, the fault will not clog up. However, the zones in the fault walls are stable because they are a function of the slow diffusion. Therefore, mineralization of fault walls is more probable because the positive saturation index prevails much longer in these zones.

Conclusion

- We successfully merges Elle and PhreeqC
- The incoming fluid pushes the pore fluid away
- Where the fluids mix the saturation index indicates that minerals like Barite can precipitate
- Two different reactive zones develop, traveling waves at the front of the incoming fluid and stable waves at fault walls.
- Mineralization will probably mainly take place at stable waves and thus in the fault walls.
- Mixing is mainly controlled by diffusion length scale – as a function of the porosity of the system
- Low porosity zones at fault walls give a length scale of about 25cm for the mineralizing stable zones



Future: density differences in fluid as function of T and c ,
diffusion as a function of T , density, and depending on species,
Taylor dispersion in diffusion as a function of advection
(reaction etc.)