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Numerical simulation of dynamic crustal-scale fluid flow

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There is abundant field evidence of non-constant fluid flow in the Earth's crust. For instance, huge veins that formed from fluids considerably hotter than their host rocks or veins formed by the crack-seal mechanism are clear examples of dynamic fluid flow. In such systems flow is localised not only in space (along fractures and high permeability beds), but also in time (i.e. in the form of fluid pulses). Most of the current conceptual and numerical fluid flow models are based on an assumed static system (e.g. a system with predefined constant permeability and boundary conditions). However, the dynamics of fluid flow can only be understood when the reaction of the system to flow (sudden opening and closing of hydrofractures) is also incorporated (Miller & Nur, 2000; Bons & van Milligen, 2001). This means that changing permeability and boundary conditions should be taken into account. Conceptually, a dynamic fluid flow model should be able to simulate cyclic successions of the following processes: (1) build-up of fluid pressure, (2) onset or re-activation of hydrofractures due to fluid overpressure, (3) fracture propagation, (4) fluid flow, (5) decrease of fluid pressure and, finally (6) closing of fractures once pressure has dropped and (7) precipitation of minerals from the fluids.

Thus, we have developed a new numerical scheme to simulate the dynamics of large-scale crustal fluid flow. The modelling platform Elle is used as a framework for the new processes, which include: (a) coupled fracture and matrix flow, which determine pressure and hydraulic head distributions in the system, and (b) dynamic update of the existing fracture permeability and creation of new hydro-fractures depending on the fluid pressure distribution.

With this numerical scheme we have developed series of simulations to understand the principles that operate in dynamic fluid flow systems as well as their flow characteristics. Preliminary results indicate that fluid flow at the crustal scale can operate as a self-organized system, in which fluid overpressure causes fast release of fluid batches that are rapidly transported upwards to regain equilibrium. Such a system can account for the existence of large vein networks that formed from fluids considerably hotter than their host rocks as well as veins formed by multiple crack and seal events.

References:

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