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Bimodal fluid flow, hydrofractures and hydrothermal ore deposits

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Fluid flow is a transport system (transport of fluid with solutes, chemical components, etc.) that can be regarded as "bimodal". At low hydraulic head gradients, fluid flow through rock pores is slow and can thus be termed "diffusional". Structures such as hydraulic breccias and hydrothermal veins indicate high fluid velocities, which can only be achieved by localized fluid transport via hydrofractures. Hydrofracture propagation and simultaneous fluid transport can be seen as a "ballistic" transport mechanism, which is activated when transport by diffusion alone is insufficient to release local fluid overpressure. The brief activation of a ballistic system locally reduces the drive, but may cause the escape of large volumes of fluid. The aim of this study is to investigate the properties of these two end-member transport modes in general and the transition between them in particular.

In our numerical model (a 2D cellular automaton), fluid is produced either at the base or in the entire model at a constant rate. Fluid production causes an increase in fluid pressure. Fluid flow in the porous matrix is modelled by pressure diffusion with the usage of a varying permeability/diffusion coefficient. When fluid pressure reaches lithostatic pressure a hydrofracture forms, simulated by breaking the element where this happens and at least one random neighbour. Permeability inside a hydrofracture is assumed to approach infinity, and fluid pressure is equalised in all connected broken elements. This can lead to more elements with excess fluid pressure and propagation of the hydrofracture. The model is thus similar to the sandpile model of Bak et al., (1988), with additional diffusional transport as in Sánchez et al. (2001).

A linear, steady-state pressure gradient is established in the absence of hydrofracturing. When fluid flux causes the pressure gradient to exceed the lithostatic one, hydrofractures form to dissipate the excess flux that cannot be accommodated by porous flow. The time-averaged vertical pressure gradient is no longer linear, but steepens at depth. Although the input flux is constant, the output flux is highly variable over time as is the mean pressure in the system. The size of hydrofractures that do not reach the surface follows a power law, as with the avalanches in the Bak et al. (1988) sand pile model. The power-law exponent is independent of the flux, once this is high enough that most fluid is transported in hydrofractures. With increasing diffusion coefficient, such large hydrofractures occur at more regular and increasingly longer time intervals, leading to a more periodical pressure flux. Our results may explain the abundance of veins at mid-crustal levels and much fewer hydrothermal deposits, typically at higher levels in the crust, produced by occasional, highly concentrated flow of large fluid volumes in hydrofractures.

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