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Dynamics of Permeability, Flow, and Ore Deposition in Overpressured, Fault-Controlled Hydrothermal Systems: Constraints from Contemporary, High Fluid Flux Faults

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Injection-driven swarm (IDS) seismicity is the characteristic response to injection of overpressured fluid into faults within low-permeability host rocks. Such swarm sequences typically have durations of days to months and involve up to thousands of predominantly microseismic slip events with moment magnitudes M_w in the range $-2 < M_w < 2.5$. These events have rupture diameters between 1 and 200 m, and slips between 0.05 mm and several mm. In contrast to mainshock-aftershock sequences, IDS sequences do not have a large rupture near the start of the sequence and do not exhibit Omori Law decay of seismicity rate with time. However, they do exhibit Gutenberg-Richter frequency-magnitude relationships with b-values ranging between 0.85 and 3.5. The largest IDS ruptures typically have $M_w < 4.5$, corresponding to a rupture diameter <1,000 m and slip up to several cm. Both natural and engineered IDS sequences exhibit diffusion-like migration of a seismicity front as a fluid-pressure front migrates away from the injection source. Natural IDS sequences have recurrence intervals of years to many decades.

Deep fluid injection experiments in low-permeability rocks demonstrate that seismicity rates correlate with injection pressure and flow rate. Additionally, injected fluid volume ΔV and cumulative seismic moment release ΣM_0 have a relationship of the form

$\Sigma M0 = \alpha G \Delta V$

where G is the shear modulus and α is a geometric factor. The cumulative moment release during natural, injection-driven swarms is used to quantify injected fluid volumes, flow rates, and flow histories associated with fluid release from a deep, intraplate fluid reservoir (Nový Kostel, Czech Republic, 2000–2011) and an upper crustal magmatic-hydrothermal system (Hakone caldera, Japan, 2001-2015). Individual IDS sequences are associated with injection of 104–105 m^3 of fluid over periods of days to weeks at rates of 20-400 Ls^{-1}. Flow histories on decadal timescales constrain fluid production rates in these systems and provide new insights about the architecture and dynamics of flow during fault-valve behaviour in the seismogenic mid- to upper crust.

Insights provided by the dynamics of seismicity style and fluid flow in engineered and natural high fluid flux faults have application to understanding flow dynamics in fault-related hydrothermal ore systems, such as orogenic Au deposits, that form by injection-driven failure in overpressured fluid regimes. The typical dimensions of lode-hosting faults indicate cumulative rupture areas between 1 and 3 km^2 and require ΣM_0 of 10^{14}-10^{15} Nm, cumulative slips less than several cm, and injection of 10^4–10^5 m^3 of fluid during each swarm. The net slip in lode-hosting faults indicates slip accumulation commonly via more than 10^3 swarms. Accordingly, net injected fluid volumes as high as 10^8 m^3 are required to produce a 50 t Au deposit. This corresponds to deposition of several 10s of kg of Au per swarm or extraction of 0.6 ppm Au from the advecting, Au-bearing fluid. Swarm recurrence intervals indicate that such deposits can form in 10^4–10^5 years; however, flow is active during only a small fraction of that time.