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Injection-driven failure and the dynamics of fluid migration in intrusion-related hydrothermal systems: Insights from coupled hydro-mechanical modelling (invited presentation - theme to be decided by L Meinert)

Stephen F Cox*, Arnd Flatten, David Beck

*The Australian National University, Canberra, Australia, Australian Capital Territory, Email: stephen.cox@anu.edu.au

In low permeability regimes, fluid migration in intrusion-related systems is controlled by permeability enhancement associated with episodic growth of extension fractures and repeated reactivation of faults. Largely aseismic opening of extension fractures is driven by fluid injection and pressurization of connected networks of hydraulic fractures at low differential stresses and severely overpressured fluid conditions. At higher differential stresses, faults are also activated seismogenically by fluid pressurization. The internal structures of faults and veins indicate that ore genesis involves repeated episodes of fluid-driven permeability enhancement and fluid migration.

Seismicity styles in contemporary, overpressured, intrusion-related hydrothermal systems are dominated by injection-driven swarm (IDS) sequences. Bursts of seismicity, associated with fluid-driven rupture propagation, involve up to thousands of slip events in the M_w range $-1 < M_w < 3$ over days to weeks; slips range from < 0.1 mm to 10 mm, over rupture lengths of several meters to several hundred meters. Cumulative rupture areas are usually less than 4×10^6 m^2. Migration of a seismicity front and the associated fluid pressure front occurs at rates up to 100s meters per day. Total moment release during intrusion-related IDS sequences indicates injection of 10^4 - 10^5 m^3 of fluid over the duration of each swarm. Swarm seismicity at Hakone (Japan) in the period 1996 - 2006 occupied a volume of 10 km^3 over a depth interval of 3 km and illustrates the scale on which fault-controlled flow can occur in intrusion-related hydrothermal systems. In these systems, ore accumulates during up to 1000s of IDS sequences, each with durations of days to months and separated by periods of years to many decades with little or no flow.

The dynamics of fluid-driven failure and fluid migration during injection of magmatic-hydrothermal fluids into low permeability host-rocks is explored using fully-coupled, 3D, hydro-mechanical simulations with continuum/discontinuum constitutive relations that incorporate the regional stress field, initial permeability, rock mechanical properties and mechanical heterogeneity associated with pre-existing faults. The models track dynamic changes in fluid pressure and stress states during fluid injection, along with permeability enhancement associated with failure. The simulations also track evolution of fluid pathways, intensity of fracture damage and fluid flux. The modelling provides insights about fluid pathways in porphyry Cu-Au(-Mo) systems and some Sn-W systems, and illustrates how the dimensions of fracture networks and ore distribution are influenced by fluid production rates, initial permeability distributions and far-field stress regimes. A major result is that injection-driven fault re-activation facilitates fast fluid transport up to several kilometers away from the injection source. Breaching of the hydrologic boundary separating an overpressured fracture network from the shallow, near-hydrostatic fluid regime leads to rapid depressurization, depletion of driving pressures in the fluid reservoir,

cessation of flow and fracture sealing. On-going fluid production and re-pressurization subsequently initiates the next phase of fluid-driven failure and permeability enhancement.

The results provide new insights about the dynamics of flow and ore deposition in magmatic-hydrothermal systems and have implications for exploration for the distal footprints of these systems.