Geophysical Research Abstracts
Vol. 18, EGU2016-14058, 2016
EGU General Assembly 2016

Dynamic typology of hydrothermal systems: competing effects of advection, dispersion and reactivity

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Genetic interpretation hydrothermal systems relies on recognition of (i) hydrothermal fluid source, (*ii*) fluid migration pathways, and (*iii*) deposition site identified by hydrothermal alteration and/or mineralization. Frequently, only the last object is of interest or accessible to direct observation, but constraints on the fluid source (volume) and pathways can be obtained from evaluation of the time-integrated fluid flux during hydrothermal event. Successful interpretation of the petrological record, that is, progress of alteration reactions, relies on identification of individual contributions arising from solute advection (to the deposition site), its lateral dispersion, and reaction efficiency. Although these terms are all applicable in a mass-conservation relationship within the framework of the transport theory, they are rarely considered simultaneously and their relative magnitudes evaluated. These phenomena operate on variable length and time scales, and may in turn provide insight into the system dynamics such as flow, diffusion and reaction rates, or continuous *vs*. episodic behavior of hydrothermal events. In addition, here we demonstrate that they also affect estimate of the net fluid flux, frequently by several orders of magnitude.

The extent of alteration and mineralization reactions between the hydrothermal fluid and the host environment is determined by: (i) temperature, pressure or any other gradients across the mineralization site, (*ii*) magnitude of disequilibrium at inflow to the mineralization site, which is related to physico-chemical gradient between the fluid source and the mineralization site, and (*iii*) chemical redistribution (dispersion) within the mineralization site. We introduce quantitative mass-transport descriptors – Péclet and Damköhler II numbers – to introduce division into dispersion-dominated, advection-dominated and reaction-constrained systems. Dispersive systems are characterized by lateral solute redistribution, driven by internal gradients and reactions in these systems are largely insensitive to the dynamics of the fluid flow. The time-intergrated fluid flux cannot be estimated from the petrological record and, in the limiting case, the net fluid flux can be zero (stagnant system in a porosity trap). This mechanism may be characteristic for Alpine-style vein assemblages and segregations in metamorphic terrains, where dissolution-reprecipitation is most likely assisted by transient gradients in stress field. Advection-dominated systems are characterized by a limited extent of chemical transport by dispersion with respect to interconnected size of the system. Progress of the alteration reactions in these systems is controlled independently by internal gradient(s) as the fluid moves through the mineralization site and magnitude of disequilibrium between the fluid and the host rock at the inflow. When the fluid flow rates remain low (e.g., dispersed metamorphic devolatilization), steady gradients along the fluid flow path exert the principal control, as commonly incorporated in the transport theory (Dolejš and Manning 2010, Ague 2014). When the fluid flow is rapid, the disequilibrium between the fluid and the host rock dictates the reaction efficiency, and the transport theory based on local equilibrium tends to significantly overestimate the net fluid flux. Advection-dominated systems with variable flow rates comprise a wide range of porosity- and fracture-controlled hydrothermal systems in intrusive and volcanic settings. With furter increase in the fluid flow rate, the advection-dominated systems evolved into reaction-constrained behavior. The mineral reaction progress is generally smaller, and the time-integrated fluid fluxes were likely much larger than petrologically estimated. These model examples illustrate that a functional description and classification of hydrothermal systems can address the causal relationships between length scales of solute (metal) sources and accumulations, and link them to time and reactivity scales necessary for the fluid transport and focusing.

Dolejš D., Manning C. E., 2010. *Geofluids 10, 20-40*. Ague J. J., 2014. *Treatise on Geochemistry 4, 203-247*.