Heat and mass transport modeling and rates of metamorphic processes

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Recent progress in understanding metamorphic processes derives, in part, from advances in our ability to apply computational modeling studies of heat and mass transport to metamorphic systems. Computational modeling of contact metamorphic systems provides a controlled laboratory to investigate the entire thermal history of a metamorphic event and rates of controlling processes. A systematic investigation of the sensitivity of key parameters e.g. permeability structure, fluid flow, fluid production, intrusion temperature, latent heat of crystallization, and multi-stage intrusions, enables examination of their impact on metamorphic processes and on P-T-X-t paths encountered by aureole rocks. Advanced visualization techniques allow the spatial and temporal variability of scalar and vector fields to be analyzed.

For example, one of the fundamental controls on crystal size distribution and porphyroblast growth in metamorphic rocks is the heating rate (dT/dt) experienced by the rocks. Two and three-dimensional heat and mass transport studies suggest that heating rates vary over four orders of magnitude during a single thermal event. While the key parameters control the absolute magnitude of the heating rate, more importantly they affect the spatial and temporal location of high heating rates. As the dominant thermal regime changes from conduction to convection, the spatial distribution of high dT/dt varies markedly. For a conduction dominated regime with isotropic permeability, high heating rates move outward symmetrically with the advance of the diffusive front. In contrast, for the convective case, high heating rates migrate with advance of the convection cell. This results in an asymmetric pattern of high heating around the intrusion.

When combined with data from a natural well-studied contact metamorphic system, thermal models provide the needed temperature-time paths for extracting kinetic data. These studies demonstrate that the assumption of a constant heating rate for extracting kinetic parameters is problematic for most natural settings because of the inherent temporal and spatial variation in thermal paths of metamorphic rocks.

Comparing natural reaction kinetics for isotopic exchange and net-transfer reactions

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Modern research in crustal processes involving metamorphism frequently employs complex physical models. wherein some quantification (or assumption) of the rate at which metamorphic reactions, or chemical exchange, proceed. Often, the assumption is made that reaction rates at these conditions are very fast (based largely on lab-based data). To test this, it has proven difficult to extract *quantitative* constraints on metamorphic reaction rates from field based analysis given the inherent complexities of nature and the challenge of constraining timescales. The results of such field based studies (e.g., Carlson et al. 1995; Baxter & DePaolo 2002; Baxter 2003) can be difficult to generalize and compare directly to eachother and to lab-based data.

Here, I compare natural rates of bulk fluid-rock isotopic exchange and net-transfer reactions. Given a generalized rate law (Rnet = k f("ΔG") where "ΔG" represents the deviation from equilibrium wrt the specific process under consideration - not necessarily expressed as a free energy), "k" is an effective rate constant into which is lumped the long list of factors that may limit or influence rates. While the f("ΔG") term will differ for every process, both isotopic exchange and net-transfer reaction processes (involving the same phases) should share the same value of "k" because they share the same list of rate-controlling conditions and processes, *excepting* the following: 1) slow product phase nucleation, 2) slow transport of net-transfer reactant species other than the isotope of interest, 3) armoring of stable phases (not consumed by net-transfer reactions) with an isotopically equilibrated rim. Field-based data indicate that differences in "k" related to factors 1 and 2 (which would tend to slow "k" for net-transfer reactions) are less than an order of magnitide. Factor 3 could slow "k" for isotopic exchange, but only in otherwise static P-T-X conditions, especially when solid-solutions are involved. The combined field data suggest that significant disequilibrium (i.e. isotopic disequilibrium and/or net-transer reaction overstepping) can persist in many metamorphic settings where P-T-X are changing.

References

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