Rates of metamorphic processes

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Given the diversity of circumstances under which metamorphism takes place, it is unsurprising that rates of metamorphism in nature span many orders of magnitude. Timescales for metamorphic processes range from thousands to tens of millions of years.

Rates of change of the driving forces for metamorphic reactions and deformation exert first-order control: it is self-evident that metamorphic processes can proceed no faster than the rate at which changes can be effected in temperature, fluid composition and stress. Heating rates, fluxes of reactive or catalytic fluids, and strain rates vary markedly between regional and contact metamorphic environments. Consequently, a fundamental kinetic distinction exists between the two environments that may be expressed by significantly larger degrees of chemical disequilibrium during contact metamorphism.

Even in regional metamorphic circumstances, however, significant chemical disequilibrium is commonplace, demonstrating that reaction mechanisms are often unable to keep pace with rates of change of driving forces. In many rocks, the kinetics of intergranular diffusion govern reaction rates, and intergranular diffusivities are highly sensitive to multiple factors that vary widely. The exponential dependence of diffusion coefficients on temperature imparts a difference in reaction rates between 400 °C and 900 °C of at least four orders of magnitude. An additional difference of roughly three orders of magnitude arises depending on whether the intergranular medium is fluid-saturated or fluid-undersaturated. Variations in diffusivity spanning four orders of magnitude arise from differences in matrix grain size in the range from 10 μm to 1 mm, and diffusivity may change markedly as matrix-grain coarsening takes place. Diffusivities are also directly proportional to solubilities in the intergranular medium, which vary by several orders of magnitude, depending on temperature, pressure, and many aspects of fluid chemistry.

In some instances, metamorphic rocks serve as sensitive monitors of the strain rates at hand-sample scale that accompany reaction and fabric development. The available data of this sort appear to define a restricted range of strain rates, but abrupt changes (smaller than a factor of ten) can be discerned within single metamorphic events.

Rates of metamorphism in nature may be fast and furious, or slow and steady, or anything in-between.