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Scales of disequilibrium and rates of equilibration during metamorphism*

WILLIAM D. CARLSON†

Department of Geological Sciences, University of Texas at Austin, Austin, Texas 78712, U.S.A.

ABSTRACT

Mounting evidence suggests that partial disequilibrium—meaning disequilibrium for some elements, but not for others—may be a common but rarely detected phenomenon during metamorphic mineral growth, even in ordinary prograde reactions that progress to completion. Detailed examination of compositional variations in garnet crystals over a range of metamorphic grade suggests distinctly different scales of equilibration for common elements, with strong temperature dependence. Under lower greenschist-facies conditions, Fe and Mg may equilibrate at hand-sample scale, whereas Mn and Ca may not equilibrate even at millimeter-scale. Although Mn may achieve hand-sample-scale equilibration under upper greenschist-facies conditions, Ca and many trivalent cations (e.g., REEs) may not do so until temperatures exceed those of the middle amphibolite facies. Even in the lower granulite facies, some elements (e.g., Y, Yb) show indications of disequilibrium at sub-centimeter-scales during garnet growth.

Analysis and numerical modeling of undisputed disequilibrium textures demonstrate that the most common impediment to equilibration during metamorphism is the sluggishness of intergranular diffusion, the same mechanism known to govern porphyroblast crystallization in many metamorphic environments. Despite this importance to petrology, few quantitative determinations exist of intergranular diffusion rates under metamorphic conditions. Using numerical simulations of coupled intergranular and intracrystalline diffusion processes in coronal textures around partially resorbed garnet crystals from the Llano Uplift, U.S.A., a very precise and relatively accurate estimate is obtained for the rate of intergranular diffusion of Al in fluid-undersaturated systems. This result and an earlier estimate for fluid-saturated systems provide bracketing values for Al diffusivity during metamorphism.