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An alternative strategy to apply equilibrium models to metamorphic rocks with disequilibrium features (GMPV Division Outstanding ECS Award Lecture)

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Metamorphic rocks evolve dynamically in response to changes in pressure (P) and temperature (T) conditions by adjusting their mineral assemblage, modes and compositions in an attempt to minimize their Gibbs free energy. The transformations are achieved by dissolution-precipitation via successive mineral reactions. Along a given P-T trajectory the evolution of metamorphic rocks can be easily modeled using the principle of Gibbs free energy minimization. Such a forward modeling technique requires a good approximation of the bulk rock composition and an appropriate thermodynamic dataset with complex solid solution models. Recent progress in the accuracy and efficiency of such techniques has had a major impact on the evolution of metamorphic petrology especially in our understanding of the physical conditions occurring in the crust. However, metamorphic rocks commonly preserve mineralogical and textural relics, such as compositionally zoned minerals. These archives are vitally important because they provide a (partial) record of the successive transformations and thus allow the reconstruction of their P-T history; but they also indicate that a rock-wide thermodynamic equilibrium clearly was not attained during the evolution of the rock. In this context, the use of an equilibrium model to understand the metamorphic petrogenesis can be questioned. It becomes necessary to quantify the compositional and textural effects on P-T estimation and to develop alternative modeling strategies that incorporate the complexity of the texture and mineral compositions.

In this contribution, I seek to establish an alternative modeling framework to decipher the P-T history of metamorphic rocks. For this purpose it is essential to provide the adapted computer tools to study and model the mineral compositional variability in link with rock textures. Thermodynamic models are applied to local domains using quantitative compositional maps. The goal is to apply the equilibrium model to the scale at which it is reasonable to assume that chemical equilibrium was achieved. It requires the identification of mineral relics and the addition of fractional crystallization models. This modeling strategy was applied to typical rock types such as amphibolite facies metapelite, migmatite, mafic and felsic eclogites. All of theses samples show a more complex record through compositional zoning of metamorphic minerals than expected. However, using a local approach it becomes possible to “read the rock” and to obtain detailed P-T paths from samples that would provide only limited information such as the peak conditions using the traditional modeling techniques. In addition, this new modeling technique allows testing of the quality of the thermodynamic predictions for any given mineral assemblage and consequently to evaluate different thermodynamic datasets and solid solution models.