Enhanced geothermal systems: Influence of thermodynamic data and activity models on predicted mineral precipitation-dissolution reactions

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A consortium of research groups from the Paul Scherrer Institut, ETH Zurich, EPF Lausanne, and the University of Bonn have been collaborating in a comprehensive basic research program on key aspects of Enhanced Geothermal Systems (EGSs). Our contribution to this GEOTHERM project focuses on fundamental investigations of thermodynamic models suitable for describing fluid-rock interactions at geothermal conditions.

Fluid-rock interactions under elevated P-T and high X are still only poorly understood. Slight variations in the input thermodynamic parameters and models can result in significant differences in the predicted mineral solubilities and stable assemblage. The correct modeling hereof, however, provides us with the information necessary to get a fundamental understanding of the permeability evolution of a geothermal reservoir, as well as of the scaling in technical installations.

A crucial requirement for modeling an EGS is the availability of thermodynamic databases and activity models tailored to geothermal conditions. Hence, we implemented into GEMS code the Pitzer formalism, which is the standard model used for computing thermodynamic excess properties of brines at elevated temperatures and pressures. This model, however, depends on a vast amount of interaction parameters which are, to a substantial extent, unknown. Moreover, the use of a high order polynomial temperature interpolation makes extrapolation unreliable, if not impossible. As an equivalent alternative we implemented the EUNIQUAC activity model. EUNIQUAC has the advantage of requiring fewer empirical fit parameters (only binary interaction parameters are needed) and uses simpler and more stable temperature and pressure extrapolations. To enhance the performance under geothermal conditions, we are currently partly reformulating EUNIQUAC, and refitting the existing parameter sets. The first results of a benchmark comparing Pitzer and EUNIQUAC applied to relevant aqueous solutions at elevated temperature, pressure and ionic strength will be presented.

Initial results from an experimental study of metamorphic nucleation

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In the study of metamorphic rocks, some details of crystallization remain murky despite decades of effort and study. Nucleation in particular is poorly understood, with numerous unanswered questions: What is the relationship of nucleation rate to driving force? What is the role of temperature? At what length scale does transport of nutrients become important? What are the surface energies that control heterogeneous nucleation (nucleation onto surfaces)? Although a theoretical framework for answering some of these questions exists, it has not been tested against any geological data.

An experimental program for the study of nucleation holds promise for answering many of these questions. Experimental nucleation is problematic for a number of reasons, chief among which is the fact that nucleation is a stochastic process. We have undertaken a pilot project to experimentally model nucleation, focusing on the reaction An + Wo = Grs + Qtz from a initial assemblage An+Wo+Qtz. This reaction is simple enough to make the experiments tractable (e.g. no worries about fluid composition or oxygen fugacity), and yet retains the basic features of reactions studied by others working on crystallization kinetics: aluminous garnet is the nucleating phase and the reaction involves multiple reactants and products. In order to remove temperature as a variable, all experiments are performed at constant temperature, and nucleation is initiated by a change in pressure only.

The experiments successfully nucleated grossular in runs within its stability field. As an example, at 1100°C and 0.2 GPa above the equilibrium pressure (1.38 GPa), the nucleation rate of grossular was very high, ~5.2 nuclei/hr/cm^3, with the grossular forming as a fine (2-10 μm) intergrowth with quartz. Nucleation rates are replicable from run to run. Our preliminary results show that there is a systematic relationship between nucleation rate and driving force. The theoretical prediction of a sharp increase in nucleation rate with driving force has been confirmed.