

THERMAL HISTORY OF METEORITES: RECORDS IN MINERAL COMPOSITIONS AND MINERAL AGES : KINETIC THEORIES, EXPERIMENTS AND APPLICATIONS. J. Ganguly, Department of Geosciences, University of Arizona, Tucson, AZ 85850, USA (ganguly@email.arizona.edu)

Introduction: I present a review of different kinetic methods for the retrieval of cooling rates of minerals in planetary samples from their compositional properties at microprobe (i.e. compositional zoning) and atomic scales (i.e. Fe-Mg ordering in orthopyroxenes, Opx), as well as the extent of resetting of their ages, as determined from mineral isochrons. A critical requirement for the application of these methods is the availability of reliable experimental data on the kinetic parameters that govern the evolution of compositional zoning, atomic ordering and closure of decay systems in minerals. I discuss the experimental procedures and data, and illustrative applications to retrieve temporal information recorded by the compositional properties and ages of minerals, and some of the wide ranging implications of the derived cooling rates.

Experimental Studies: The diffusion kinetic studies that we have carried out to address planetary problems fall into two classes: (a) Inter-diffusion experiments using diffusion couples in Piston-Cylinder apparatus [1] and (b) tracer diffusion experiments in one atmosphere gas mixing furnace using oriented samples for anisotropic minerals [e.g. 2, 3, 4, 5]. The analytical techniques for the measurements of the induced diffusion profiles involve (a) step or beam scanning in a microprobe across the interface of the diffusion couple and (b) depth profiling in a SIMS for the tracer diffusion experiments.

The kinetic parameters of Fe-Mg ordering between the M1 and M2 sites in Opx have been retrieved by isothermal annealing as well as continuous cooling experiments and determining the change of Fe-Mg ordering state from single crystal X-ray data.

Theory, Modeling and Illustrative Applications: The observed diffusion induced compositional zoning in minerals may be modeled to retrieve the time scale over which the zoning developed on the basis of the appropriate solutions of the diffusion equation and diffusion kinetic data. As illustrative examples, I discuss the retrieval of cooling rates from modeling of compositional zoning across core-overgrowth interface in relict Semerkona olivine chondrules [6] and augite exsolution lamellae in clinopyroxenes in non-cumulate basaltic eucrites [5, 7]. The modeling requires correction for the diffusion anisotropies, and in the case of the eucrites, additional correction for the convolution effects in microprobe spot analyses.

The quenched Fe-Mg ordering states in Opx are modeled on the basis of a first order rate law and numerical simulations that depict the evolution of the ordering state as function of cooling rate. The cooling rate is varied until the quenched ordering state in the simulation matches the observed data. Illustrative applications include low temperature cooling rates of stony iron meteorites, including mesosiderites [8, 9]. A combined modeling of Fe-Mg zoning and ordering in Opx grains in the latter group revealed a complex cooling history that was previously unknown.

The closure temperature-cooling age theory of Ganguly and Tirone [10, 11], which builds on the work of Dodson [12], has been applied to calculate cooling rates from ^{53}Mn - ^{53}Cr cooling ages of olivine grains in the pallasite Omolon and Opx in a cumulate eucrite, Serra de Magé. These results yield the depth of the core-mantle boundary of pallasites to be ~ 30 km in a parent body of at least ~ 100 km radius, and a thickness of the eucrite crust of ≥ 30 km in the commonly accepted parent body, asteroid Vesta.

The recently reported difference between the Lu-Hf [13] and Sm-Nd [14] mineral ages of Shergottite RBT 04262 seems to strongly argue against the notion of shock re-setting of mineral ages [15] of these Martian samples. Instead, the age difference is most likely the result of difference in closure temperatures of the two decay systems and slow cooling [16].

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