The Jilin Thermal History Paradox

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Introduction: The Jilin chondrite fall on March 8, 1976 – the largest ever recorded –was seen by some as a harbinger of dynastic change. While Mao's death and the arrest of the Gang of Four later that year fit that mythology closely, a real lasting legacy is the unique challenge to understand the varied thermal histories revealed by the different Jilin fragments. Prior $^{40}Ar/^{39}Ar$ age spectra [1,2] documented a parent body that had experienced thermal degassing events at ~2.2 and ~0.5 Ga. We revisited Jilin using high resolution step-heating with temperature cycling and isothermal duplicate steps, which optimizes the extraction of both the kinetic (E and D_o/r_o^2) and domain distribution parameters (relative size, ρ and volume fraction, ϕ).

Results: Four release patterns of three fragments of Jilin (K-1, K-2 and K-4) are characterized by smoothly increasing ages that rise to a peak at 4.4 Ga, followed by a drop and then subsequent rise in age. The first ~75% of gas release corresponds to a uniform K/Ca of ~0.3 which subsequently drops by over factor of 100. Knowledge of the Jilin mineralogy and phase chemistry permits us to correlate the first degassing component to an intermediate feldspar and the second to clinopyroxene.

We devised a code that permits forward and inverse modeling to age and Arrhenius spectra samples for samples containing 1) multiple diffusion domain (MDD) sizes [3], 2) multiple E's [4], and 3) episodic and slow cooling histories. We note that while Arrhenius plots without isothermal duplicates [1,2] yield apparently well-correlated arrays with $E \approx 45$ kcal/mol, the associated $\log(r/r_o)$ plot shows extreme non-monotonic behavior demonstrating that this value is an artifact of the laboratory heating schedule. Instead, an E=67 kcal/mol, derived from thermal cycling and consistent with Ar diffusion in plagioclase [5], reconciles the isothermal duplicate steps to yield a monotonically increasing $\log(r/r_o)$ over the feldspar portion of gas release. Note that use of the apparent linear arrays on Arrhenius plots produced by monotonically step-heating samples containing MDD size variations yields meaningless T-t information due to accidental alignments produced as smaller fractions preferentially degas.

Summary: Our simulations using the Arrhenius parameters defined by the lab degassing readily reproduce the feldspar portion of gas release but fail to capture the oldest ages (~4.4 Ga) in the pyroxene portion of release. Three possible scenarios permit the full age spectra to be reconciled with their Arrhenius plots and an estimated thermal history if prior to 2.2 Ga Jilin experienced: 1) feldspar size reduction in response to impact, 2) pyroxene coarsening following that event, or 3) a heating episode of extraordinarily high temperature and short duration (i.e., 4000 K and 3 μsec). We are investigating the implications of the latter with respect to possible effects of shock heating.

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