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Collisional devolatilization of planetary building blocks.

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Differentiated planetary bodies are characterized by the depletion of highly and moderately volatile elements relative to solar compositions and chondrites. Many processes during their formation could contribute to this depletion – one particular case occurs during the collisional stage following gas disk dissipation. During this stage, planetesimals and planetary embryos gravitationally perturb each other's orbits, leading to energetic impacts between bodies of varying sizes. The energy released in these collisions is sufficient to melt the colliding bodies and thereby drive the evaporation of moderately volatile elements such as K and Na. However, the extent to which collisional energy contributes to melting and volatile depletion remains debated [1].

In this work, we carry out a series of N-body simulations to reconstruct the collisional history of planetesimals and protoplanets under different initial conditions. Using scaling laws from Nakajima et al. (2021) [2], we estimate the melt produced in each impact event and then integrate the accumulated impact melting over time. We find that although collision speed profiles vary with initial setups, the impact energy is consistently high enough to repeatedly melt planetesimals and protoplanets. We analyze devolatilization of K after melt and construct the cumulative devolatilization effect to quantify volatile loss during the collisional stage [3]. We will present a comparison between the observed volatile depletion patterns of rocky bodies in the solar system and the results of the simulations, along with a discussion on the necessity of additional processes, e.g. heating by short-lived radionuclides and devolatilization of pebbles during pebble accretion [4], to explain various levels of volatile depletion. This study carries important implications for understanding planetary formation and the origins of chemical heterogeneity within solar system rocky bodies.

[1] C. Sturtz et al. (2022), Icarus 385, 115100.
[2] M. Nakajima et al. (2021), EPSL 568, 116983.
[3] C. A. Meredith et al. (2025), EPSL 669, 119580.
[4] H. S. Wang, A. Johanson et al. (2026), submitted.