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Tracing volatile processing in the early Solar System using halogens in chondrule mesostasis

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Variations in halogen abundances in chondritic materials provide insight into how volatile elements were processed and redistributed in the protoplanetary disk prior to planet formation. Fluorine (F), chlorine (Cl), bromine (Br), and iodine (I) are highly incompatible in silicate minerals and preferentially partition into melts and fluids, allowing us to use their systematics to trace volatile incorporation into planetesimals and early Earth. Chondrule mesostasis glass, which represents the final crystallisation product of chondrules, preserves these signatures and provides a direct record of halogen behaviour during melting, cooling, and potential exchange with the surrounding nebular environment.

We have investigated halogen behaviour in chondrule mesostasis by measuring abundances of F, Cl, Br, and I, using secondary ion mass spectrometry (SIMS). Major-element compositions of mesostasis and coexisting silicate phases were determined using scanning electron microscopy (SEM) and electron probe microanalysis (EPMA). Our dataset comprises 46 chondrules from Antarctic carbonaceous chondrites (Dominion Range [DOM] 08006; Elephant Moraine [EET] 92105) and primitive ordinary chondrites (EET 90628; Grosvenor Mountains [GRO] 06054; Meteorite Hills [MET] 00452; MET 96503).

Mesostasis from carbonaceous chondrites contains 0.37-12.2 ppm F, 0.22-290 ppm Cl, 0.002-0.83 ppm Br, and 30-432 ppb I. In contrast, ordinary chondrites exhibit wider ranges of 0.2-118 ppm F, 0.3-2255 ppm Cl, 0.001-2.5 ppm Br, and 2-273 ppb I. Within L-group ordinary chondrites, Br concentrations appear to increase systematically while I concentrations decrease with increasing metamorphic grade from type 3.05 to 3.6, resulting in a strong correlation between Br/I ratio and metamorphism. This trend suggests modification of halogen signatures by diffusion or dissolution in metasomatic fluids. Halogen abundances observed in chondrule mesostasis from ordinary and carbonaceous chondrites are much lower than those in enstatite chondrites [1] implying fundamental differences in halogen carriers, redox conditions, or vapour-melt exchange during chondrule formation across distinct regions of the protoplanetary disk.

These results place new constraints on halogen availability during chondrule formation and subsequent mobility during parent-body processing. They provide important insights into the distribution of volatile elements in early Solar System solids, with implications for models of Earth's volatile element inventory.

References: [1] Baker, E., Jones, R. H., & Villeneuve, J. (2023).