Proton Irradiation Processing of Early Solar System Solids

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Introduction: Young Stellar Objects (YSOs) were active suppliers of energetic particles in the early solar system. Particles, primarily protons, with keV-MeV energies may have interacted with early solar system solids resulting in chemical, atomic, and morphologic changes. An investigation is underway to determine how energetic protons interact with silicates, primarily olivine, and how these changes are reflected in the meteorite record. Of particular interest are possible chondrule and matrix formation mechanisms.

Particle accelerators can simulate the radiation environment associated with YSOs by depositing energy over length scales proportional to the particle energy. Using Monte Carlo derived ion ranges, calculations have determined the irradiation conditions necessary for heating and possibly melting silicates via proton irradiation. These conditions conform well to those predicted to occur in YSOs [1,2,3], and could possibly be considered a chondrule melting mechanism [3,4]. In lieu of complete melting, significant heating may be responsible for volatile loss, analogous to beam heating in an electron microprobe.

A series of preliminary experiments were performed to investigate proton irradiation effects in olivine. The work has produced several results not initially considered; the first being that centimeter-sized olivine crystals explode into millimeter sized fragments when irradiated with high-flux proton beams. This result has implications for an irradiation induced comminution process in the early solar nebula. A second observation is the minimal threshold energy required to activate silicon. Olivine irradiated with 2 MeV protons (~1μA of current) results in significant prompt gamma radiation. The radiation is likely due to the $^{29}Si(p,\beta+)^{30}P$ reaction. The ^{30}P decays via a β+ particle with an approximate 2.5 minute half-life; the anti-matter annihilation results in the production of two 511 keV γ-rays. It is unknown what residual isotopic signature would remain after such a relatively low-energy proton irradiation. A third observation is the deposition of carbon on the periphery of the beam-target interface. In vacuum systems, carbon is available from oils in mechanical pumps; in space high partial pressures of CO_2 in the irradiation environment could result in the deposition of a fine grained carbonaceous component on irradiated silicates. Both carbonaceous and fine grained material deposited during irradiation could be both crystalline and amorphous due to varying degrees of radiation damage.

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