Mineralogy and chemistry of stardust samples

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Comets are primitive bodies that likely preserve the fundamental building blocks of the solar system. The return of samples from comet Wild-2 by the Stardust mission provides an opportunity to study some of the earliest solar system solids in detail. We report here transmission electron microscopy observations of several Stardust particles.

Terminal particles were extracted from aerogel keystones of an ~2 mm long "carrot-shaped" track (C2067 T112), and an ~2 mm long "ginseng-shaped" track (C2061 T113). The single terminal particle from T112 consists of an ~10 µm rounded grain of forsteritic olivine. Energy-dispersive x-ray spectra show that the core of the grain is Fo99 - x-ray mapping reveals a slight enhancement in Fe towards the rim of the grain to Fo97. The forsterite is strained and shows a high density ($2x10^{10}/cm^2$) of oriented planar defects along (100). One small inclusion of chromite was observed.

Multiple terminal particles have been extracted and analyzed from T113. The mineralogy of these particles is similar and is dominated by coarse-grained enstatite (En90) that is largely orthoenstatite with numerous clinoenstatite lamellae. One particle (TP1) contains minor forsterite (Fo88). The enstatite also contains small inclusions of diopside with % levels of Al, Cr and Fe. The diopside has Cr/Fe at. ~3. Two of the terminal particles (TP1,TP3) contain nepheline intergrown with the enstatite. Diffraction analysis and dark-field imaging show that the nepheline is polycrystalline and EDX analyses show no detectable K. Some of the nepheline grains are partly vesiculated.

Nepheline is a rare phase in primitive meteorites and its petrogenesis is generally attributed to Na metasomatism of aluminosilicate glass or crystalline feldspar, and we infer a similar origin for the nepheline in the Stardust particles. The planar defects in the forsteritic terminal particle and some of the pyroxene microstructures likely result from shock. It is unknown whether the shock effects resulted from processes that occurred on Wild-2 or if they formed in response to the capture event.

Extraction of grain and phase boundary material properties from zoned garnets

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In recent studies, we used the repository potential of garnet in combination with high-resolution analytical techniques (i.e. EBSD, FE-EMPA and TEM/FIB) and numerical simulations in order to gain new knowledge about the nature of chemical pathways in terms of geometrical (e.g. boundary width) and physical properties (e.g. diffusivities and solubilities), which is fundamental in understanding reaction kinetics and mass transfer in the Earth's deep crust and upper mantle.

Reactions of type A + plagioclase (Pl) $\rightarrow$ garnet (Grt) + C often form Grt rims (~20 µm wide) along reactant boundaries and we found that the necessary mass transfer across reaction rims is amplified by the formation of subgrains perpendicular to the reaction fronts, which allows for short-circuit diffusion. Information about the contribution of grain boundary diffusion to bulk material flow in Grt is stored during the formation of asymmetric growth zonings and micron-scale compositional variations along grain and phase boundaries. Our evaluation of these compositional patterns by diffusion modelling allows for the derivation of D_i^{gb}/D_i^{vol} ratios and rim growth rates. Reaction progress needs the transfer of material through the interior of reacting Pl towards the reaction fronts. About 100 nm wide pores in Pl and Grt-Pl phase boundaries, which both are filled with a non-crystalline material, suggest that a coupled diffusion and dissolution/precipitation process, during which internal and surface dissolution/precipitation formed new nano-scale pathways and a non-crystalline transport medium, likely enhanced mass transfer in Pl and along Grt-Pl phase boundaries.

Information about phase boundary material properties is also stored in the zoning of Grt porphyroblasts, which formed during the retrograde Fe-Mg exchange between Grt and biotite. If temperature falls below a limiting value during cooling, non-equilibrated rim compositions start to develop along Grt-Qtz phase boundaries due to insufficient chemical transport rates. Because the extent of non-equilibrated rim compositions reflects the transport capacity of the present interganular medium, our simulations by diffusion modelling of observed compositional patterns formed during cooling at Grt-Bt-Qtz triple junctions allows for the extraction of boundary material properties.