Low-Ca pyroxenes in Comet Wild 2: Origins from Chondrule-forming Regions and as Nebular Condensates

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Introduction: Unraveling the origins of particles in comet Wild 2 is the primary goal of the NASA Stardust (SD) mission that returned samples of a comet believed to have formed in the Kuiper Belt (KB). Some relatively well-preserved particles have chondrule-like textures and chondrule-like oxygen isotope compositions supporting a high temperature inner Solar System (SS) origin [1-3]. However, ~1/2 of all Wild 2 particles are single monomineralic olivine or pyroxene or simple mixtures of the two [4], thus many SD grains lack petrographic and petrologic context information which complicates efforts to understand their origins.

Here we use the minor elements Al, Cr and Mn in SD low-Ca pyroxenes to provide insights into their source regions. To facilitate this study we compiled nearly 600 Lpx chemical analyses from the literature from chondrites of petrographic types 3-6 from 8 groups including CM, CO, CV, CR, H, L, LL and Acfer 094 [5-14]. To our knowledge this represents the largest compilation of Lpx compositions from such a diverse group of chondrites to date. Our study provides evidence that most Lpx grains in the Wild 2 samples formed by igneous processes similar to chondrules in primitive chondrites (type 3) and some likely formed by gas-solid condensation in the nebula. The data imply that the Lpx comet grains did not experience significant thermal metamorphism and thus were not incorporated into parent bodies prior to comet Wild 2 and were likely transported directly to the KB after formation in the nebula.

Techniques/Methods: Sixty five Lpx grains from 16 SD tracks, ~1/2 of which were isolated monomineralic fragments, were analyzed for major and minor elements by standard TEM/EDX techniques using a Tecnai TF20 TEM/STEM located at the University of Washington.. To prepare the grains for TEM analyses, the samples were flattened in aerogel keystones or bulb wall fragments and embedded in acrylic or epoxy resin and microtomed to <70nm thickness and mounted on Cu or Au TEM grids supporting 10nm C films.

Results: A literature compilation of 499 analyses of Lpx minerals from chondrules in type 3 chondrites (8 groups) shows a distinct separation from Lpx minerals in types 4-6 chondrites (82 analyses) [5-14] on a Al_2O_3 vs Cr_2O_3 plot. In chondrules from type 3 chondrites, Lpx falls above 0.4 wt% Cr_2O_3 and has variable Al_2O_3 while Lpx in types 4-6 chondrites is metamorphically depleted in both Al and Cr. Within the type 3 groups, Lpx in ordinary chondrites (OC) can be distinguished from carbonaceous chondrites (CC) because of generally lower Al_2O_3 concentrations. Al and Cr systematics provide evidence for the origin of many Lpx grains in Wild 2 samples similar to chondrules. Fifty five Wild 2 Lpx minerals (Mg# 77-99, MnO_{ave} = 0.8 wt%) fall in the type 3 region while 10 Lpx (9 of 10 have Mg# > 99 and MnO < 0.25 wt%) plot in the depleted Cr and Al types 4-6 region, but the latter is not a result of metamorphism.

Discussion: Elevated Cr and Al in 55 Lpx grains (15 tracks) from Wild 2 demonstrates that these pyroxenes are similar to Lpx in chondrules from type 3 OC and CC groups. Oxygen isotopes previously measured on 8 of these Wild 2 Lpx grains (Al_2O_3 > 0.9 wt%) have negative $\Delta^{17}O$ values (ave= -2.3 ‰) showing CC affinities and may be aligned with CR chondrites [15-17]. Because of their compositional purity (low Fe abundances and low Al, Cr and Mn) the 9 of the 10 remaining Wild 2 Lpx grains are not likely associated with equilibrated chondrites (types 4 -6) which have high Fe and Mn abundances, but are more consistent with a gas-to-solid condensate origin. Unlike Lpx in equilibrated OCs the low Cr and Al in these Wild 2 Lpx grains is not due to diffusion or feldspar growth but likely was inherited during condensation. Oxygen isotope analyses previously obtained on 3 of the Wild 2 Lpx grains show that two have large negative $\Delta^{17}O$ values ($\Delta^{17}O$ = -21.3 to -22.3 ‰) [15], a result that is also consistent with a condensation origin.

Conclusions: Minor element abundances in isolated and other Lpx grains from Wild 2 indicate: 1) most Lpx from Wild 2 likely originated in CC chondrule-forming regions with a smaller proportion from OC chondrule regions, 2) Wild 2 Lpx did not experience significant thermal metamorphism suggesting the grains did not reside in parent bodies prior to transport to the outer SS and 3) ~15% of Wild 2 Lpx plausibly have condensate origins. Oxygen isotopes previously obtained on some of the Wild 2 grains in this study support these conclusions [15-17].

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