HIGHLY REDUCED FORSTERITE AND ENSTATITE FROM STARDUST TRACK 61: IMPLICATIONS FOR RADIAL TRANSPORT OF E ASTEROID MATERIAL.

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Introduction: The Stardust Mission returned a large fraction of high-temperature, crystalline material that was radially transported from the inner solar system to the Kuiper Belt [1,2]. The mineralogical diversity found in this single cometary collection points to an even greater number of source materials than most primitive chondrites. In particular, the type II olivine found in Wild 2 includes the three distinct Fe/Mn ratios found in the matrix and chondrules of carbonaceous chondrites (CCs) and unequilibrated ordinary chondrites (UOCs) [3]. We also find that low-Ca pyroxene is quite variable (~Fs_{3-29}) and is usually indistinguishable from CC, UOC, and EH3 pyroxene as well. However, occasional olivine and pyroxene compositions *are* found in Wild 2 that are inconsistent with chondrites. The Stardust track 61 terminal particle (TP) is one such example and is the focus of this study. It's highly reduced forsterite and enstatite is consistent only with that in Aubrites, in which FeO is essentially absent from these phases (<~0.1 wt.% FeO) [4].

Samples and Methods: We have made $>10^3$ EPMA analyses of olivine and >500 of pyroxene (5-30 μm) isolated in chondrite matrix. These particles are analogous to the coarse-grained Stardust TPs. Our matrix data includes EPMA analyses from CI1 (Ivuna and Orgueil), CM2 (Murchison, Mighei, Maribo, El-Quss Abu Said, and Kivesvaara), anomolous CMs (Acfer 094 and Bells), CR 3.0 (MET 00426 and QUE 99177), CH3 (SaU 290), CO 3.0 (ALHA77307), CV 3.0 (Kaba and Bali), CK 3.0 (Ningqiang), Kakangari, LL3 (Semarkona and Krymka), EH3 (ALHA81189, ALHA77156), and an enstatite chondrite clast from Almahata Sitta. We are also being allocated two TEM grids from each Wild 2 particle that has been harvested from the Stardust aerogel collectors and subsequently microtomed. To date, we have performed TEM/EDXS measurements (with 500s count times) on 27 particles harvested from 16 tracks, but this study focuses on the ultra-microtomed section C2009,6,61,0,2 from the track 61 TP. EPMA analyses from Aubrites are taken from [4,5].

Results: The track 61 TP is a ~5 μm long and 3 μm wide assemblage of amorphous silicate, forsterite, Fe metal with minor Si and Cr, one enstatite crystal, and two unusual Fe/Ni metal grains ~0.3 μm in diameter. These grains are extremely Ni-rich (Fe/Ni ~1.48) and contain crystalline inclusions (~10 nm) that may be Fe/Ni/Cr phosphides and sulfides, although we have not yet determined the state of P and S. Analyses were obtained for 5 forsterite crystals and 1 enstatite crystal (~0.4-0.5 μm) from C2009,6,61,0,2. Even the highly reduced olivine and pyroxene found in our unequilibrated EH3 chondrites contains measurably more FeO than in the Aubrites and the track 61 TP, which have < ~0.10 wt. % FeO. Although some equilibrated enstatite chondrites have FeO content in enstatite at this level [6], the CaO content and absence of Cr_2O_3 appears to be more consistent with aubrites. Minor element plots are shown in Figs. 1-4. In particular, Fig. 1 shows the pronounced depletion of Cr_2O_3 from low-Ca pyroxene in the reduced materials (EH3, Kakangari, Aubrites, and the track 61 TP) relative to the CCs. UOCs have Cr_2O_3 contents similar to the CCs. We conclude that the Aubrites and the track 61 TP are compositionally distinct from all chondrites and that the Aubrite olivine and pyroxene are indistinguishable from that found in the track 61 TP.

Fig 1: Fe/Cr trends of low−Ca pyroxene

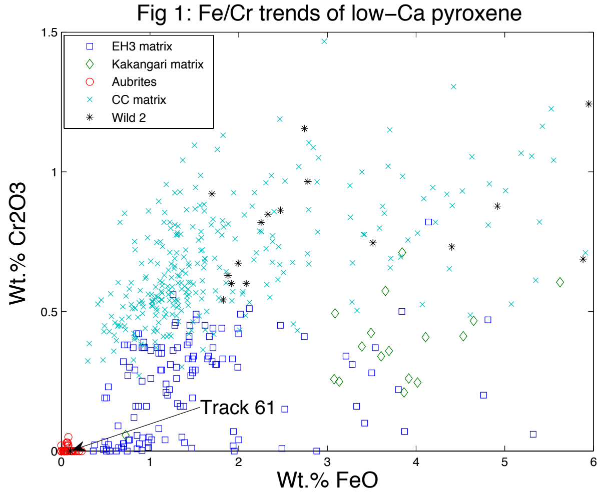


Fig. 2: Fe/Ca trends of low–Ca pyroxene

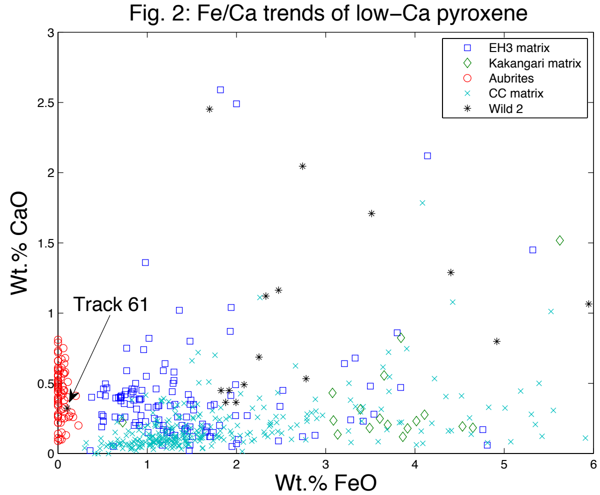


Fig. 3: Fe/Mn trends of olivine

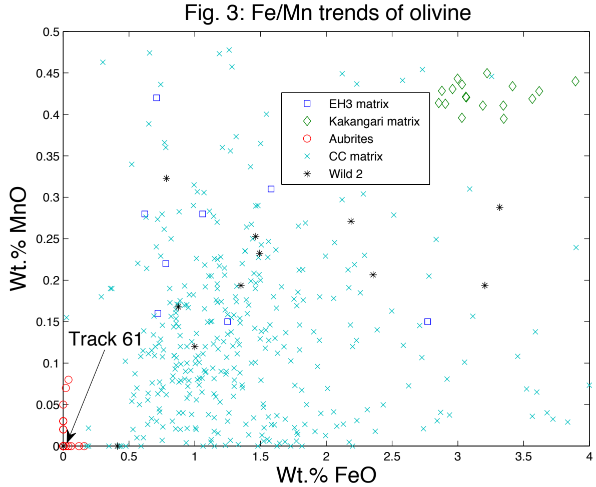
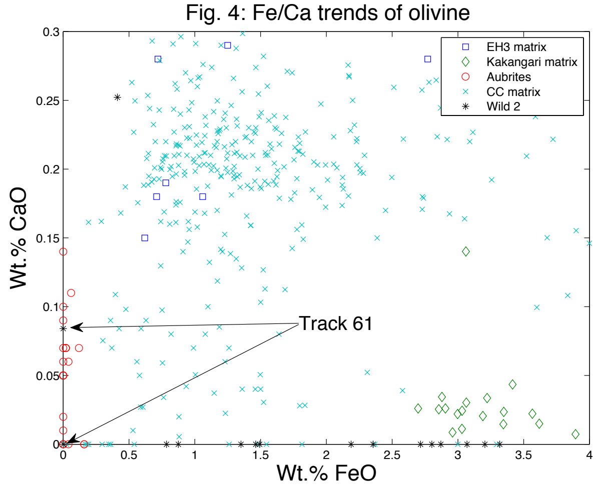


Fig. 4: Fe/Ca trends of olivine



Discussion: The presumed parent bodies of Aubrites are the E type asteroids, which are members of the high-inclination Hungaria asteroid family in the inner main asteroid belt [7]. Modeling by [8] demonstrates that the initial E-belt (1.7-2.1 AU) population of asteroids may have been the source of today's Hungaria asteroids. This model requires that ~99.6-99.9% of the initial E-belt population was destabilized during the late heavy bombardment (LHB). To account for today's observed abundance of Hungaria asteroids, the model then requires that the initial E-belt's population was ~20-80% as abundant as today's main asteroid belt. Such a massive disruption of localized material should have spread the E-belt's material widely across the solar system.

Aubrite-like and enstatite chondrite lithic clasts have been reported in Kaidun [9] and Sutter's Mill [10], indicating possible mixing between C and E type asteroids, as suggested by [10]. In addition, we now have evidence to support early radial transport of E asteroid material to the Kuiper Belt. These combined observations are consistent with the model in [8]. Giant impacts between E asteroids and other planetary bodies during the LHB may have contributed E asteroid material to the outer main asteroid belt and the Kuiper Belt.

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