SOURCE REGIONS FOR COMET WILD 2 FE0-RICH OLIVINES: COMBINED FE-MG-MN SYSTEMATICS AND OXYGEN ISOTOPES

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Introduction: Determining the origin of captured comet particles was a major goal of the Stardust (SD) mission. Mineralogical studies have shown that many of the comet Wild 2 particles are single mineral grains [1,2] and as such lack contextual information with other materials in the comet complicating interpretations on their origins. This is unlike chondrites where petrographic relationships between components can be established. FeO-rich olivines are one of the most common mineral types observed in Wild 2 samples [1,2]; we have observed these minerals in all bulbous (type B) tracks that we have studied. They comprise an important subset of minerals in comet Wild 2 and like FeO-rich olivines in type II chondrules in chondrites require high oxidizing conditions to form.

In this investigation we use Fe-Mg-Mn relationships combined with high precision O isotopes [3, 4, 5] from 12 FeO-rich olivines from 4 Stardust tracks to provide insights into their possible source regions. This combination of independent chemical and isotopic studies should provide a powerful means toward the goal of understanding the origins of these Wild 2 particles and provide insight into bulk chondrite isotopic studies which have shown that non-carbonaceous and carbonaceous meteorites may have originated in distinctly different regions of the Solar System (SS) [6].

Samples and Analytical Techniques: Twelve FeO-rich olivines, ranging in size from ~3 to 23 µm, were extracted from 4 SD keystones [7], flattened between glass slides and embedded with acrylic resin. The tracks and fragments studied include T22/F7, F8, F10, F12; T77/F1, F4, F5; T149/F1, F3, F11a, F11b; T191/F6. Ultramicrotome sections, typically < 70 nm thick, were cut from potted butts and examined on Cu or Au TEM grids with a Tecnai TF20 STEM located at the University of Washington. EDX analyses were obtained with a thin window EDAX X-ray detector and quantified using mineral and NIST standards and Cliff-Lorimer factor correction techniques [8]. Typical errors are <5% for Fe and Mg and ~30% for Mn. Bright-field imaging and electron diffraction were also employed to study the grains.

Oxygen three-isotope ratios of these particles were obtained by using the WiscSIMS IMS 1280 and were previously reported in [3-5]. Data are shown in Fig. 1. The four fragments from track 22 fall within the region represented by bulk R chondrites, though, one of two analyses, from fragment 7, falls on the TFL. Two of three particles from T77 also plot above the TFL and fall in or near bulk ordinary chondrites. One of the two analyses of T77/F4 plots below the TFL. Track 149 consists of four FeO-rich olivines which plot mostly along the TFL and slightly below. The single FeO-rich olivine from track 191 plots slightly above the TFL.

Results: A plot of Fe/Mn vs Fe/Mg of the 12 FeO-rich olivines is shown in Fig. 2. Four solid black lines emanating from the origin show constant Mg/Mn ratios and represent the bulk CI, R, OC and CH chondrite groups [9]. Portions of the bulk CO and CR lines are also shown. Most olivines from T22, T77 and T191 overlap the CI, R and OC lines while olivines from T149 have distinctly different Mg/Mn ratios and fall on or close to the CH line. Also shown in the figure are the range of olivine compositions predicted from a cooling, crystallizing liquid from a CI bulk source using MELTS modelling [10], at equilibrium conditions, 75% initial S loss and an fO2 of ΔIW+1 (orange curve).

Discussion: The purpose of plotting olivine compositions on a Fe/Mn vs Fe/Mg plot (Fig. 2), normally used for showing bulk chondrite compositions, is to understand the significance, if any, why single olivines fall along a trend on this diagram. The co-linearity and nearly complete overlap of most FeO-rich olivines from tracks 22, 77 and 191 with the MELTS equilibrium crystallization curve suggests these olivines may have formed from high temperature melts. The potential melts could have formed from bulk CI, R or OC liquids which would plot at higher Fe/Mg ratios on the CI, R or OC lines. Their widely varying Fe/Mg ratios, ranging from 0.2 – 0.68, are consistent with olivines that may have crystallized at different temperatures, perhaps during rapid cooling. The olivines have Fe/Mn ratios ranging from 26 – 79, a range that is similar to type IIA chondrule olivines in OCs (Fe/Mn = 25 – 70, ave = ~44) [11]. This compares to average Fe/Mn ratios of 99 in FeO-rich olivines in CO chondrites [11]. The large range of Fe/Mg ratios in the olivines in T22, T77 and T191 is comparable to ordinary chondrites reported by [11].

Because of the similar Mg/Mn ratios of the CI, OC and R groups, we cannot discriminate between the groups on the basis of Fe-Mg-Mn systematics alone. O isotopes (Fig. 1), however, indicate that the olivines in tracks 77 and 191 may have links with OC source regions while the olivines in track 22 are more consistent
with an R chondrite source. However, higher Fo contents in olivines from track 22 (Fo$_{71.88}$) are generally higher than R chondrite olivines (Fo$_{60}$). This may indicate that track 22 olivines are less equilibrated than olivines in R chondrites, though they are largely $^{16}$O-poor compared to chondrules in primitive R3 chondrites [12]. Also, Fo contents in olivine from track 77 (Fo$_{57.46}$) are lower than typical OC olivine (Fo$_{70}$). Alternatively, these particles were derived from unknown sources not depleted in Mn similar to OC and R.

The higher Mg/Mn ratios of olivines from track 149 suggest an origin from a CH type source region. The O isotopic variability of these olivines is similar to some porphyritic and cryptocrystalline chondrules from Acfer 214, a CH chondrite [13]. However, because the measured O isotopic compositions from Acfer 214 are from bulk chondrules rather than single olivines, it is unclear how suitable this comparison is. We note that metal grains are present in track 149.

The present work has focused on FeO-rich olivine, a material that was found to be unexpectedly abundant in an outer SS body. These ferrous olivines formed in highly oxidizing conditions, possibly in nebular regions analogous to those that formed materials that are characteristic to both OC and carbonaceous chondrite source regions.

![Fig. 1](image1.png)

**Fig. 1.** $^{17}$O isotope compositions of 12 FeO-rich olivines from 4 SD tracks. The bulk R and OC fields are shown with the black ovals. TFL = terrestrial fractionation line, PCM = primitive chondrite mineral line [16], CCAM = carbonaceous chondrite mineral line [17].

Conclusions: Fe-Mg-Mn systematics combined with high precision O isotopes indicate that FeO-rich olivines from 4 SD tracks may have links to OC, R and/or CH chondrite source regions. This mix supports isotopic studies that show a fundamental dichotomy between non-carbonaceous and carbonaceous meteorite groups that were likely derived from the inner and outer SS, respectively. MELTS modelling further demonstrates that the FeO-rich olivines may have formed at high temperatures similar to some chondrules.