EQUILIBRATED AGGREGATES IN COMETARY IDPS: INSIGHTS INTO THE CRYSTALLIZATION PROCESS IN PROTOPLANETARY DISKS.. L. P. Keller and S. Messenger. Robert M. Walker Laboratory for Space Science, ARES, Mail Code KR, NASA Johnson Space Center, Houston, TX 77058 (Lindsay.P.Keller@nasa.gov).

Introduction. Processes occurring within protoplanetary disks partly convert amorphous interstellar silicate grains into crystalline grains [e.g. 1,2]. The details of the transformation mechanism(s) and the subsequent transport of the crystalline grains from the hot inner part of the disk to cooler regions are poorly constrained [3]. Having formed in the coldest, most distant region of the Solar System, comets harbor well preserved remnants of these processes, and provide an important counterpoint to inner solar system materials that comprise meteorites. Initial studies of cometary materials returned by the Stardust spacecraft reveal abundant refractory minerals whose origins are traced to the inner solar system [e.g. 4], indicating efficient transport of processed materials to the outer reaches of the solar nebula.

The best preserved samples of original nebular materials may be found in anhydrous chondritic porous (CP) interplanetary dust particles (IDPs) whose origins are linked to short-period comets [e.g. 5]. We are analyzing the crystalline grains within cometary IDPs to gain insights into the crystallization processes in the early solar nebula. Many of the crystalline silicates in IDPs occur as single crystals with compositions and microstructures that are most consistent with high T condensation processes [6]. In previous studies we have shown the great majority of crystalline silicates have solar O isotopic compositions, and thus likely formed in the inner regions of the solar system [7]. Crystalline silicates in IDPs also occur in polycrystalline grains that are referred to as equilibrated aggregates (EAs) [8]. We are exploring the chemistry, mineralogy and isotopic characteristics through coordinated analyses of EAs in IDPs to determine if they represent some of the earliest examples of grain growth and coagulation in the early nebula.

Methods and Samples. Nanometer-scale quantitative compositional maps of equilibrated aggregates in microtome thin sections of chondritic porous IDPs (L2005AL5, L2011B10, W7029C28, L2005AA7) were obtained using a JEOL 2500SE 200 keV field-emission scanning-transmission electron microscope (STEM) equipped with a Noran thin window energy-dispersive X-ray (EDX) spectrometer. Following EDX mapping, the sections were subjected to O isotopic imaging with the JSC NanoSIMS 50L.

Results. Equilibrated aggregates are 0.1-2.0 μm sized irregularly-shaped, polycrystalline objects that are a component of cometary IDPs (Fig.1a). Their abundance in individual IDPs is highly variable from a few vol.% to nearly the entire volume of an IDP. The EAs consist predominantly of crystalline grains with a simple mineralogy dominated by Mg-rich crystalline silicates (enstatite and forsterite), pyrrhotite, Mg-Al, Si-rich mesostasis, and minor diopside (Fig. 1b). We have not observed metallic Fe in any of the EAs studied to date. The constituent grains in EAs are euhedral and range from 50-200 nm in size, but are typically 100 nm in size and frequently show equilibrium grain boundaries. The mesostasis is an amorphous aluminosilicate (Na- and K-free) without vesicles. In two cases, we observed amorphous rims surrounding the aggregate (rims occur on the crystalline silicates) that are consistent with irradiation of these objects prior to accretion into their parent bodies.

We measured bulk chemical compositions for 30 EAs. The element/Si ratios vary widely by factors of 2 to 3 (Fig. 2). The average bulk composition is subsolar for most major elements (O/Si=2.97, Mg/Si=0.87, Al/Si=0.06, S/Si=0.31, Ca=0.05, and Fe/Si=0.44). The average composition of EAs is more Mg-rich and Fe-poor compared to the average compostion of GEMS grains in IDPs (Mg/Si=0.67, Fe/Si=0.56) although there is considerable overlap. All of the measured equilibrated aggregates had O isotopic compositions that were indistinguishable (±50‰) from solar.

Discussion. While the mineralogy and morphologies of EAs show they were never molten, their textures are consistent with formation by subsolidus annealing of amorphous precursors. It is unlikely that the precursors of EAs were interstellar amorphous silicates because their inferred compositions are quite distinct from EAs. GEMS grains are more likely precursors to EAs because they have very similar chemical and isotopic compositions. Brownlee et al. [9] proposed that GEMS grains were the amorphous precursors to EAs in IDPs based on controlled heating experiments which produced EA-like objects from GEMS grains. Keller et al. [10] observed a continuum of GEMS morphologies from porous to solid GEMS to equilibrated (crystalline) aggregates and proposed that this reflects a sequence of preaccretional thermal annealing at subsolidus temperatures (below the thermal stability limit of pyrrhotite).

If GEMS grains were the precursors to EAs, then there are a number of implications that follow. First, EAs are larger than individual GEMS grains (or interstellar grains), so there had to be significant grain coagulation/agglomeration that occurred before the heating event(s) that formed the crystals. Second, nanophase FeNi metal is common in GEMS grains but is absent in EAs, which is consistent with heating under oxidizing conditions. Our compositional data suggest that EAs have lower bulk Fe abundances than GEMS grains. If this trend is confirmed by additional analyses, it indicates that Fe was lost from GEMS during the annealing process. We have proposed that most GEMS grains are late-stage nonequilibrium nebular condensates [10] and thus the formation of EAs must have occurred at a later stage. The heating either occurred close to the early Sun or in regions heated by nebular shocks as proposed by [3].

Conclusions. The presence of equilibrated aggregates in cometary IDPs provides evidence for grain coagulation and annealing in the protoplanetary disk. Compositional data indicate that GEMS grains are the likely precursors to equilibrated aggregates.

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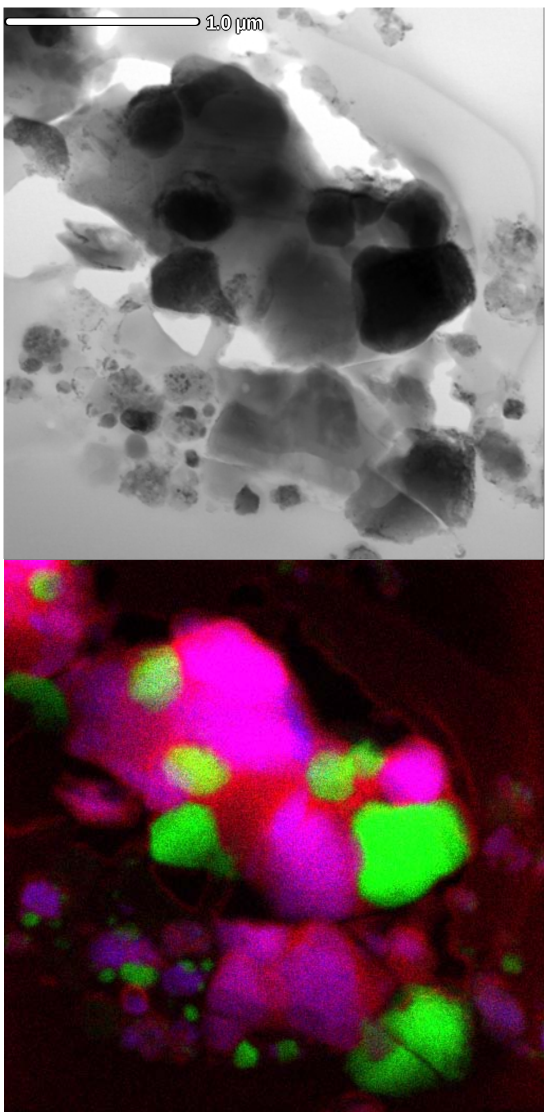

Figure 1. a) A brightfield TEM image of an equilibrated aggregate in IDP L2011B10, and b) an X-ray map of the same EA where the magenta colored grains are enstatite ($MgSiO_3$), while the green grains are pyrrhotite ($Fe_{1-x}S$). The red areas correspond to the interstitial SiO_2-rich mesostasis.

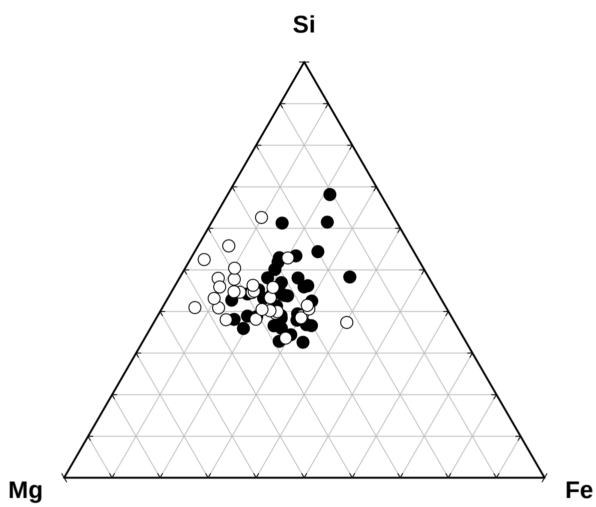

Figure 2. Mg-Fe-Si ternary plot (in at.%) showing the compositions of equilibrated aggregates (open circles) compared to GEMS grains in the same particles (filled circles).