ASSEMBLAGE OF PRESOLAR MATERIALS AND EARLY SOLAR SYSTEM CONDENSATES IN CHONDRITIC POROUS INTERPLANETARY DUST PARTICLES.

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Introduction: Anhydrous chondritic porous interplanetary dust particles (CP IDPs) contain an assortment of highly primitive solar system components, molecular cloud matter, and presolar grains [1]. These IDPs have largely escaped parent body processing that has affected meteorites, advocating cometary origins. Though the stardust abundance in CP IDPs is generally greater than in primitive meteorites, it can vary widely among individual CP IDPs. The average abundance of silicate stardust among isotopically primitive IDPs is ~375 ppm [2] while some have extreme abundances up to ~1.5% [3]. H and N isotopic anomalies are common in CP IDPs and the carrier of these anomalies has been traced to organic matter that has experienced chemical reactions in cold molecular clouds or the outer protosolar disk. Significant variations in these anomalies may reflect different degrees of nebular processing.

Refractory inclusions are commonly observed in carbonaceous chondrites. These inclusions are among the first solar system condensates and display ^{16}O-rich isotopic compositions. Refractory grains have also been observed in the comet 81P/Wild-2 samples returned from the Stardust Mission [4] and in CP IDPs [5], but they occur with much less frequency.

Here we conduct coordinated mineralogical and isotopic analyses of CP IDPs that were characterized for their bulk chemistry by [6] to study the distribution of primitive components and the degree of nebular alteration incurred.

Methods: The IDPs U2015D21 (~17 μm) and W7013E17 (~18 μm) were chosen for this study. Their bulk C contents and silicate mineralogy were determined by scanning electron microscopy/EDX [6]. Both IDPs contain mixtures of olivine and pyroxene. The IDPs were embedded in epoxy and microtomed to produce ~70 nm thick slices that were deposited onto Cu TEM grids. The mineralogy and chemical compositions of the IDP components were determined by transmission electron microscopy (TEM). The JSC JEOL 2000FX TEM and 2500SE STEM were used to acquire bright-field and dark-field images and quantitative X-ray maps of appropriate slices.

Isotopic analysis of the slices was then conducted by isotopic imaging using the JSC NanoSIMS 50L. To strengthen the grids for isotopic analysis, the backside of the TEM grids were coated with Au. The isotopes ^{16}O, ^{17}O, ^{18}O, ^{12}C^{14}N, ^{12}C^{15}N, and ^{28}Si were measured simultaneously as negative secondary ions in electron multipliers. An electron flood gun was used to reduce sample charging. The IDP slices were analyzed using a ~0.8 pA, <100 nm Cs^+ primary beam. San Carlos olivine and 1-hydroxy benzotriazole hydrate were analyzed as O and N isotopic standards, respectively. A total area of 255 $μm^2$ (6 slices) of U2015D21 and 170 $μm^2$ (3 slices) of W7013E17 was measured for their O and N isotopic compositions. One slice of each IDP were analyzed both by TEM and NanoSIMS.

TEM Results: The lack of magnetite rims on mineral grains in both IDPs suggests minimal atmospheric entry heating. U2015D21 is a typical anhydrous CP IDP composed of very fine (20-200 nm) crystalline and amorphous silicate grains bound together by thin layers of carbonaceous material. U2015D21 is dominated by GEMS (glass with embedded metal and sulfides) grains which make up to 50% of the analyzed area, followed by sulfide, enstatite, diopside, and olivine grains. Two enstatite whiskers (1000×50 nm) are also observed.

W7013E17 is relatively compact for anhydrous IDPs, but no hydrous phases are detected. The crystalline constituents are enstatite, forsterite, sulfide and diopside grains, 10-1000 nm in size. These grains have partial euhedral shapes and show equilibrium grain boundaries. The amorphous phase is Si-rich with Mg-Al-Na mesostasis throughout the fine crystalline grains. GEMS grains are comparatively minor. W7013E17 is therefore dominated by equilibrated aggregates (EAs) commonly reported in CP IDPs [7] which are believed to form by annealing of GEMS grain precursors [8].

NanoSIMS Results and Discussion: *Molecular cloud matter.* IDP U2015D21 is particularly enriched in ^{15}N, with bulk $δ^{15}$N values ranging from ~80-230‰. The ^{15}N-rich regions constitute widespread areas and discrete hotspots 100-1200 nm in size, covering ~7% of the total analyzed area. The $δ^{15}$N values ranged from 175-1200‰. The N isotopic compositions are consistent with models of chemical reactions in dense molecular clouds [9]. IDP W7013E17 also contains ^{15}N-rich regions, though they were not nearly as numerous or anomalous as in U2015D21. The bulk $δ^{15}$N value was ~20‰ and the hotspots had values of 170-370‰. These ^{15}N-rich regions had sizes 190-350 nm and made up only ~0.5% of the area measured. The lower abundance and $δ^{15}$N values of molecular cloud matter in W7013E17 might imply a higher degree of parent body alteration than U2015D21, but this is not supported by the TEM analysis. The organic matter in W7013E17 could thus have experienced greater nebular alteration.

Presolar grains. One ~170 nm presolar grain was identified in U2015D21 with an ^{17}O enrichment (δ^{17}O = 1225±155‰, 1σ) and normal ^{18}O/^{16}O (Fig. 1). This isotopic composition is consistent with formation in a red giant star. This slice was on top of a grid bar and chemical information could not be obtained. However, the grain is likely a silicate based upon the ^{28}Si$^-$/^{16}O$^-$ ratio. The presolar grain abundance in U2015D21 is estimated to be ~92 ppm.

W7013E17 contained an ^{18}O-poor presolar silicate grain (δ^{17}O = 220±150‰, δ^{18}O = -300±50‰) with a ^{28}Si$^-$/^{16}O$^-$ ratio similar to surrounding material. This isotopic composition suggests an origin in a low-mass red giant star. One 240 nm, ^{15}N-poor region was also identified (δ^{15}N = -325±40‰). EDX mapping could not be conducted on this grain, but the NanoSIMS analysis reveals a highly elevated ^{28}Si$^-$/^{16}O$^-$ ratio relative to neighboring material. This strongly suggests the grain is SiC. The ^{15}N/^{14}N of this grain falls in the range observed for presolar SiC grains from asymptotic giant branch stars. While presolar SiC grains are well studied in meteorites, only two other presolar SiC have been identified in IDPs [3, 10] and one in a Wild-2 sample [11]. The presolar silicate and SiC abundances in W7013E17 are ~270 and ~200 ppm, respectively.

^{15}N-rich CP IDPs have been noted to have high presolar grain abundances [2]. IDP W7013E17 does not share the same display of ^{15}N-rich regions as U2015D21, yet it has a higher presolar grain abundance. Previous study of IDP W7027E6 [12] indicated low bulk δ^{15}N values (<40‰) similar to W7013E17 and a high presolar grain abundance of ~2200 ppm.

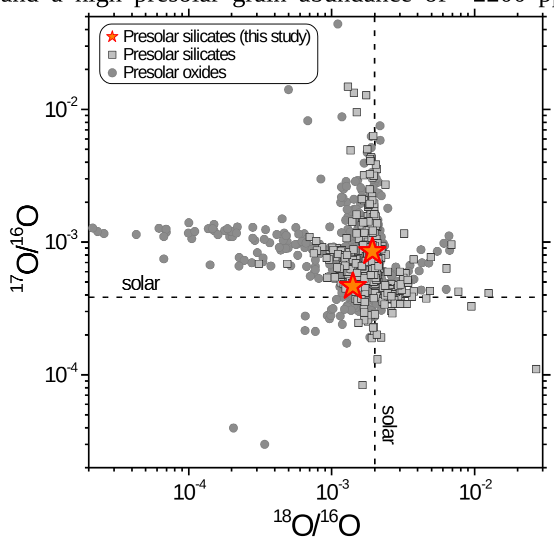

Figure 1. Oxygen isotopic ratios of presolar oxides and silicates [13], and presolar silicates from this study.

Thus we do not observe a clear correlation between the abundances of ^{15}N-rich matter and presolar grains.

^{16}O-rich grains. Two ^{16}O-rich grains were identified in U2015D21 (δ^{17}O = -100±40‰, δ^{18}O = -85 ±17‰; δ^{17}O = -125±27‰, δ^{18}O= -80±12‰). No chemical information was obtained for these grains but the ^{28}Si$^-$/^{16}O$^-$ ratios suggest they are silicates. The degree of ^{16}O enrichment is similar to that observed for refractory inclusions in meteorites [14], CP IDPs [5], and Wild-2 samples [4], which have δ^{17}O and δ^{18}O values extending to ~ -40‰ along the carbonaceous chondrites anhydrous minerals (CCAM) mixing line. (Fig. 2). These high temperature condensates formed in the inner solar system and were transported to the asteroid belt and well beyond to the Kuiper belt.

The IDPs studied here contain a diverse assemblage of primitive materials having very different sources and histories. The accretion of matter from other stars, the outer solar nebula, and the inner solar system denote mixing processes over large distances. The identification of ^{16}O-rich grains and presolar SiC, rare phases in IDPs, emphasizes the primitive nature and uniqueness of these two samples.

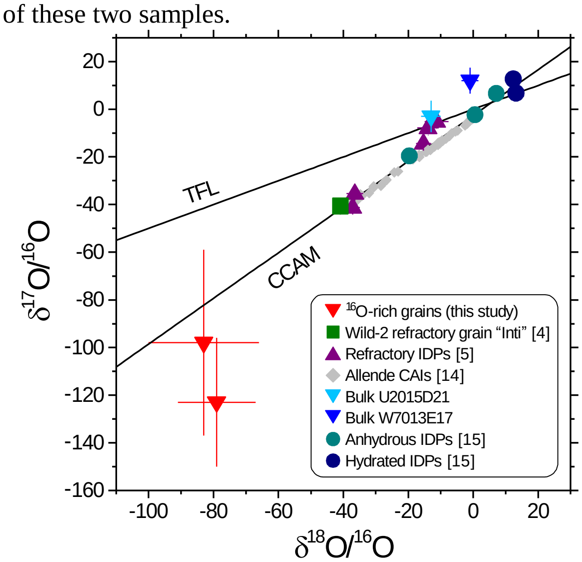

Figure 2. Oxygen isotopic composition of refractory solar system components and bulk IDPs [15].

References: [1] Messenger S. et al. (2006) *MESS II*, 187. [2] Floss C. et al. (2006) *GCA, 70,* 2371. [3] Busemann H. et al. (2009) *EPSL, 288,* 44.[4] McKeegan K.D. et al. (2006) *Science, 314,* 1724. [5] McKeegan K.D. (1987) *Science, 237,* 1468. [6] Thomas K.L. et al. (1993) *GCA, 57,* 1551. [7] Bradley J.P. (1994) *GCA, 58,* 2123. [8] Brownlee D.E. et al. (2005) *LPS, 36,* A2391. [9] Charnley S.B. and Rodgers S.D. (2002) *ApJ, 569,* L133. [10] Stadermann F.J. et al. (2006) *GCA, 70,* 6168. [11] Messenger S. et al. (2009) *LPS, 40,* A1790. [12] Nguyen A.N. et al. (2014) *LPS, 45,* A2351. [13] Hynes K.M. and Gyngard F. (2009) *LPS 40,* A1198. [14] Clayton R.N. et al. (1977) *EPSL, 34,* 209. [15] Aléon J. et al. (2009) *GCA, 73,* 4558.