HISTORY OF NEBULAR PROCESSING TRACED BY SILICATE STARDUST IN IDPS. S. Messenger[1], L.
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Introduction: Chondritic porous interplanetary
dust particles (CP-IDPs) may be the best preserved
remnants of primordial solar system materials, in part
because they were not affected by parent body hydro-
thermal alteration. Their primitive characteristics in-
clude fine grained, unequilibrated, anhydrous mineral-
ogy, enrichment in volatile elements, and abundant
molecular cloud material and silicate stardust [1-4].
However, while the majority of CP-IDP materials like-
ly derived from the Solar System, their formation
processes and provenance are poorly constrained.

Stardust abundances provide a relative measure of
the extent of processing that the Solar System starting
materials has undergone in primitive materials. For
example, among primitive meteorites silicate stardust
abundances vary by over two orders of magnitude (<10
− 200 ppm) [5,6]. This range of abundances is ascribed
to varying extents of aqueous processing in the mete-
orite parent bodies. The higher average silicate stardust
abundances among CP-IDPs (>375 ppm; [7]) are thus
attributable to the lack of aqueous processing of these
materials. Yet, silicate stardust abundances in IDPs
also vary considerably. While the silicate stardust ab-
undance in IDPs having anomalous N isotopic compo-
sitions was reported to be 375 ppm, the abundance in
IDPs lacking N anomlies is < 10 ppm [7]. Furthermore,
these values are significantly eclipsed among some
IDPs with abundances ranging from 2,000 ppm to
10,000 ppm [4,5,8]. Given that CP-IDPs have not
been significantly affected by parent body processes,
the difference in silicate stardust abundances among
these IDPs must reflect varying extents of nebular
processing.

Here we present recent results of a systematic coor-
dinated mineralogical/isotopic study of large cluster
IDPs aimed at (1) characterizing the mineralogy of
presolar silicates and (2) delineating the mineralogical
and petrographic characteristics of IDPs with differing
silicate stardust abundances. One of the goals of this
study is to better understand the earliest stages of evo-
lution of the Solar System starting materials.

Experimental: The IDP studied here (AA4) is a
15 μm fragment of a very large IDP L2036 cluster #4
which is known to have high abundances of silicate
stardust (~2,000 ppm) [9]. Fragments of this cluster
IDP display a wide range in compositions, from almost
pure carbonaceous material (>90%) to more classic

CP-IDP mineralogy. In general, this cluster is particu-
larly fine grained, with typical grain sizes <0.5 μm.

The particle was embedded in elemental S for ul-
tramicrotomy and sliced into 70 nm sections that were
deposited onto C-coated TEM grids. Some sections
were placed onto Cu grid bars for isotopic measure-
ments, while most sections were reserved for TEM
characterization prior to isotopic measurements. This
approach enables parallel efforts for isotopic mapping
to establish silicate stardust abundances as well as sys-
tematic coordinated mineralogical mapping by TEM
followed by isotopic analysis. Quantitative X-ray maps,
bright-field, and dark-field images were obtained from
the thin sections using a JEOL 2500SE field-emission
STEM.

Isotopic measurements were performed with the
JSC NanoSIMS 50L ion microprobe. O and N isotopic
images were taken simultaneously, acquiring images of
$^{16}O^-$, $^{17}O^-$, $^{18}O^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$, $^{28}Si^-$, and $^{24}Mg^{16}O^-$ in
multidetection with electron multipliers. The images
were obtained by rastering a 0.1-0.2 pA, <100 nm Cs^+
beam over 10 - 15 μm fields of view. The images were
repeatedly acquired for a total of 20 − 30 image layers
for each analysis. The duration of each analysis ranged
from 8-20 hours. Sample charging was minimized with
the use of an electron flood gun. 10 μm grains of San
Carlos olivine and 1-hydroxy benzotriazole hydrate
placed near each sample served as external isotopic
standards for O and N, respectively.

Results & Discussion: TEM investigation of AA4
showed it to be fine grained (<0.5 μm) and dominated
by an assemblage of polycrystalline grains, or equili-
brated aggregates (EAs). Other phases observed in-
clude rare GEMS (glass with embedded metal and sul-
fide) grains, forsterite, and an enstatite platelet. Car-
bonaceous material is rare. Minor magnetite rims are
observed on some grains in the section, indicating
moderate atmospheric entry heating.

Twelve microtome sections of AA4 were subjected
to O and N isotopic imaging, and four of these sections
were previously mineralogically mapped by TEM. A
total of five presolar silicate grains were identified
among these sections, yielding an estimated abundance
of 1,600 ppm. The isotopic compositions of the preso-
lar silicate grains fall within the range of presolar
oxides and silicates [4-7,10], with three having large
^{17}O-enrichments and normal $^{18}O/^{16}O$ ratios (Group 1

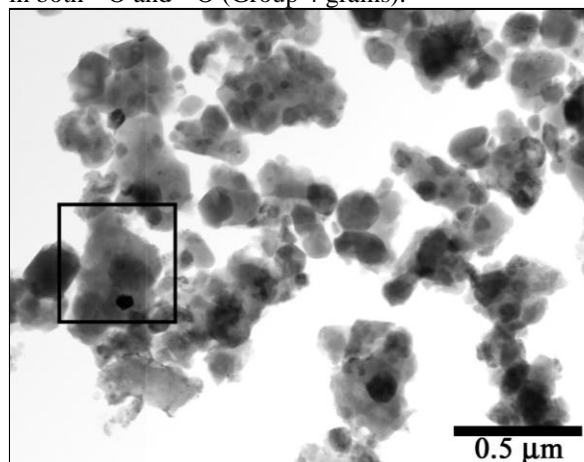grains) and two grain having pronounced enrichments in both ^{17}O and ^{18}O (Group 4 grains).

Figure 1: Brightfield TEM image of a section of AA4 containing a presolar silicate-dominated EA grain (boxed) that is associated with numerous equilibrated aggregates.

Two of the presolar grains were identified in sections previously mapped by TEM, and both grains are equilibrated aggregates (Figures 1 & 2). The bulk composition of the first presolar EA (Fig. 1) has Mg/Si = 0.9, Fe/Si=0.4, S/Si=0.24 (at. ratios) with minor Al, Ca and Ni. The second presolar EA (Fig. 2) is slightly more Mg-rich with Mg/Si=1.1, Fe/Si=0.24, S/Si=0.16 and higher Ca and Al compared with the previous grain. Chemical maps of the second grain indicate the Ca,Al-rich region is a probable diopside grain.

The fact that the two presolar equilibrated aggregates are found within an IDP fragment having an unusually high abundance of EAs suggests that all of these grains experienced a thermal annealing process. The setting of this annealing event was most likely in the solar nebula; it is unlikely to have resulted from atmospheric entry heating owing to the presence of intact GEMS grains and the minor development of magnetite. Furthermore, other fragments of the parent cluster IDP also do not appear to be strongly heated and have low abundances of EAs. Although the nature of the precursors of the presolar EAs cannot be established with certainty, the bulk compositions of both presolar EA grains fall within the (wide) range of GEMS grains [11].

Equilibrated aggregates are commonly observed in IDPs as 0.1- 2 μm-sized, irregularly shaped, polycrystalline objects. Their abundance varies among IDPs from a few vol. % to nearly the entire IDP mass [12]. EAs have simple mineralogy dominated by Mg-rich crystalline silicates (enstatite and forsterite), pyrrhotite, Mg-Al, Si-rich mesostasis, and minor diopside. While the mineralogy and morphologies of EAs show they were never molten, their textures are consistent with

formation by subsolidus annealing of amorphous precursors.

Spectroscopic observations of young stellar systems reveal a progressive change in the composition of dust from predominantly amorphous silicates (presumed to be interstellar grains) into crystalline grains [13,14]. The details of the transformation mechanism and the subsequent transport of the crystalline grains from the hot inner part of the disk to cooler regions are poorly constrained.

Owing to their formation in cold, distant region of the solar nebula it was proposed that cometary olivine grains formed by annealing of interstellar amorphous silicates, rather than condensation from a high temperature gas [15]. It is interesting to note that the two presolar EAs identified here are polymineralic assemblages that do not contain olivine and have also likely undergone a phase transformation while preserving their isotopic identity. Additional coordinated mineralogical studies of IDPs with differing silicate stardust abundances may reveal further details about the nebular evolution of the Solar System starting materials.
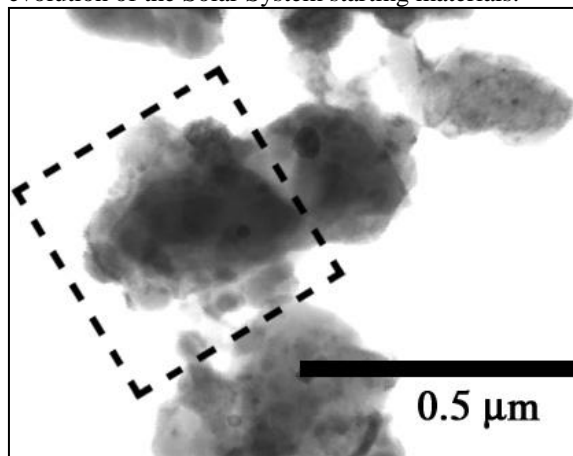

Figure 2: Brightfield TEM image of a presolar equilibrated aggregate (boxed).

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