Amorphous Silicates in Early Solar System and Presolar Materials. Lindsay P. Keller and Scott Messenger, Robert M Walker Laboratory for Space Science, Astromaterials Research and Exploration Science Directorate, Mail Code KR, NASA Johnson Space Center, Houston, TX 77058. Lindsay.P.Keller@nasa.gov.

Introduction. Studies of early solar system processes have naturally focused on chondritic meteorites because they contain the oldest (dated) solar system solids. However, much of the earliest history of the solar system, predating the formation of CAIs and chondrules, is shrouded by extensive parent body hydrothermal alteration that has reworked the matrix mineralogy of all chondrites. Cometary materials have escaped significant parent body alteration, and thus may represent the most representative assemblage of the original solar system starting materials. Samples of cometary materials include chondritic-porous (CP) interplanetary dust particles (IDPs) and Stardust mission samples. Both of these sample sets are likely to have originated from the Kuiper belt, a collection of pre-cometary bodies residing in a fundamentally different regime of the solar system (>40 AU from the Sun) than meteorites (2.0 – 3.3 AU).

Typical CP "cometary" IDPs are highly porous particles that consist of fine-grained crystalline silicates, amorphous silicates, Fe-Ni sulfides, and minor refractory minerals all encased by an abundant organic-rich carbonaceous matrix. The constituent grains of IDPs are much finer-grained (100 nm ~ 1 μm) than typical meteorite matrix grains. Amorphous silicates in CP IDPs are highly abundant, accounting 30 – 60 wt % of their mass. Most of these amorphous silicates are classified as GEMS grains (glass with embedded metal and sulfides). GEMS grains are abundant in the least altered solar system materials, but apparently absent in meteorites. A clear understanding of their origins is central to understanding the origins of the first solar system solids.

Results and Discussion..GEMS grains are submicrometer, rounded grains that consist of nanophase inclusions of FeNi metal, FeNi sulfides, and numerous trace phases in a Mg-Al-Fe-Si-rich glassy matrix. Coordinated transmission electron microscope and ion microprobe measurements show that a few percent (<5%) of GEMS have non-solar O isotopic compositions and are thus demonstrably presolar (stardust). A systematic survey of the bulk elemental compositions of GEMS grains shows that their average S/Si, Mg/Si, Ca/Si, and Fe/Si ratios are approximately ~60% of solar values, although their average Al/Si ratio is solar. Compositional mapping reveals that most GEMS grains are aggregates composed of even smaller subgrains with diverse compositions. The subgrain compositions are dominated by two major components, silica-rich and FeS-rich grains that likely formed as late stage non-equilibrium condensates. The bulk compositions of GEMS grains can be explained largely by variable mixtures of these two subgrain compositions. We observe a continuum of GEMS morphologies from porous to solid GEMS to equilibrated (crystalline) aggregates that may in fact reflect a sequence of preaccretional thermal annealing at subsolidus temperatures (below the thermal stability limit of pyrrhotite).

These combined isotopic, bulk chemical, mineralogical studies show that GEMS grains are a collection of objects with different origins and histories. Differing explanations for their origins have been proposed, including direct condensation and extensive radiation processing (atomic scale sputtering and accretion) in the interstellar medium. The observed compositional heterogeneity in most GEMS is unlikely to have resulted from extensive radiation processing, which would tend to homogenize their elemental distributions *via* ion-mixing. GEMS grains and crystalline components in cometary IDPs have complementary elemental compositions that, taken together, nearly match solar composition [1]. This relationship suggests that most GEMS grains are also condensates (non-equilibrium) from a solar gas that had previously (at higher temperatures) fractionally condensed crystalline silicates and metal [1]. The elemental and isotopic data for GEMS grains suggest that most (>80 %) formed in the early solar nebula. A subset of GEMS grains (10-20%) has chemical and isotopic compositions that are consistent with models for homogenized interstellar silicates [1]. Since many GEMS grains appear to be aggregates or partially annealed, these grains may have experienced variable degrees of processing after their formation.

An unexpected conclusion of this work is that the majority of cometary materials formed at high temperatures in the early solar system. However, the Kuiper belt is unlikely to have experienced the temperatures necessary to have formed silicates by condensation. We propose that large-scale radial dust transport within the protoplanetary disk is necessary to reconcile the intimate mixture of presolar, interstellar, and inner solar system materials that are observed in cometary IDPs [2]. A similar conclusion was reached to explain the occurrence of high temperature minerals (e.g. forsterite, melilite, osbornite) in Stardust samples from comet Wild-2 [3].

Astronomical IR spectra of comets [4] and young stars [5,6] are dominated by amorphous silicates that are generally considered unprocessed interstellar amorphous silicates. Here we propose that amorphous and crystalline silicates form in abundance in the inner regions of young stellar objects and are efficiently transported throughout protoplanetary disks. It is likely that only laboratory studies of these primitive materials can clearly identify the formation processes and origins of the most common constituents of the starting materials.

The presolar GEMS and the probable interstellar GEMS grains in IDPs predate the formation of CAIs, chondrules and matrix and may have been precursors to these meteoritic materials. Calculations show that average GEMS chemical compositions are highly normative for Fe-bearing olivine and so they also may have been a precursor component to the fine-grained fayalitic olivine common in the matrices of primitive carbonaceous chondrites.

Conclusions: Amorphous silicates were widespread constituents of the early solar system. Rare amorphous silicate stardust grains survived intact, but most were destroyed or heavily altered by shock and irradiation processes in the interstellar medium. Current evidence indicates that amorphous silicates were also efficiently produced in the early solar nebula.

References. [1] Keller, L. P. and Messenger, S. (2004) *LPS XXXV*, #1985. [2] Keller, L. P. and Messenger, S. (2005) The Nature and Origin of Interplanetary Dust: High-temperature Components, In *Chondrites and the Protoplanetary Disk* (Eds. Krot, Scott & Reipurth) *ASP Conf. Series* 341, 657-667. [3] Brownlee, D. E. *et al*. (2006) *Science*, 314, 1711-1716. [4] Hanner, M. (2003) The Mineralogy of Cometary Dust, In *Astromineralogy* (Ed. Henning), Springer, 171-185. [5] Meeus, G., Waters, L.B.F.M., Bouwman, J., et al. (2001) *A&A* 365, 476. [6] Bouwman, J., Meeus G., de Koter, A., (2001) *A&A* 375, 950.
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