TEM AND NANOSIMS STUDY OF HYDRATED/ ANHYDROUS PHASE MIXED IDPs: COMETARY OR ASTEROIDAL ORIGIN? K. Nakamura, S. Messenger and L.P. Keller Robert Walker Laboratory for Space Science, NASA Johnson Space Center, Houston TX 77058 (keiko.nakamura1@jsc.nasa.gov)

Introduction: Chondritic interplanetary dust particles (IDPs) are subdivided into (1) particles that form highly porous aggregates (chondritic porous 'CP' IDPs), and (2) smooth particles ('CS' IDPs) [1-3]. Infrared (IR) spectroscopy has been a valuable tool for non-destructively determining the bulk mineralogy of IDPs. Most IDPs fall within three distinct IR groups: (1) olivine-rich particles, (2) pyroxene-rich particles, and (3) phyllosilicate-rich particles [4]. From the IR studies, IDPs dominated by anhydrous minerals tend to be fine grained (CP) [5], while phyllosilicate-rich IDPs are mostly CS [4]. CP IDPs have been linked to cometary sources based on their compositions, spectral properties, and atmospheric entry velocities [6]. Since no spectral signatures of hydrated minerals have been detected in comets, CS IDPs are thought to derive from primitive asteroids [6].

Transmission electron microscopy (TEM) studies have revealed that the mineralogical distinctions between CP and CS IDPs are not always clear. Previous investigators have reported trace amounts of hydrous minerals in dominantly anhydrous particles [7,8]. A better understanding of these particles will help to elucidate whether there is a genetic relationship between anhydrous and hydrated IDPs, provide insight into the earliest stages of aqueous alteration of primitive materials, and may help to determine whether comets have experienced any aqueous processing.

Here we report a combined TEM and isotopic imaging study of an unusual anhydrous IDP with hydrated phases.

Samples and Methods: The IDP we studied, L2005K7, (32 μm in size) was previously embedded in low-viscosity epoxy as part of an earlier Fe-sulfide study using TEM [9]. The IDP was classified as a hydrated type [9]. We obtained new ultramicrotome thin sections (~70nm thickness) of this particle for a more detailed mineralogical study with a JEOL 2000FX TEM equipped with a Noran energy-dispersive X-ray detector (EDX) analysis system. One ribbon of 6 sections was laid down on a Au substrate for isotopic imaging with the Washington University NanoSIMS ion microprobe. Two of these sections were subjected to O isotopic imaging (to search for presolar oxides or silicates) and subsequently for C and N isotopic imaging (to search for remnant molecular cloud material).

In the first set of analyses, we simultaneously acquired images of $^{16,17,18}O^-$, $^{28}Si^-$, and $^{24}Mg^{16}O^-$ with electron multipliers. The second set of images included $^{12}C^-$, $^{13}C^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$ and $^{28}Si^-$. In both cases, images were acquired in a 15 μm field of view using a 16 keV, 2 pA Cs^+ primary ion beam, which had a nominal beam diameter of 100nm.

Mineralogy: Individual mineral grains more than 50 nm in size of two entire thin sections of the IDP were analyzed for their chemical compositions. The mineral identifications were confirmed by electron diffraction and high-resolution lattice fringe imaging. Forsterite (~200 nm in size), pyrrhotite platelets (~ 3um) and small spherules (~ 100nm), are ubiquitous in the sections. GEMS (glass with embedded metal and sulfides) are abundant and clumped into certain regions coated by amorphous carbonaceous material (Fig.1). Enstatite crystals are severely damaged/altered and have amorphous rims with the similar chemical composition as the crystalline cores. An enstatite whisker is observed on the surface of the particle attached to hydrated region (Fig. 2). The hydrated region (~ 5 % of the section) comprises fine-grained phyllosilicates grown onto sulfide platelets. The phyllosilicates are poorly crystallized with typically 5-20 nm crystallite size (Fig. 3), and have lattice fringes that are easily destroyed by a defocused electron beam. The chemical composition and basal spacing of 13 - 14 Å show that they are smectite. Some amorphous silicates have aluminosilicate composition. An amorphous grain has a core with forsterite composition and Si-rich glass mantle with tiny Fe-Ni sulfide inclusions. Magnetite clusters, which are typically a main phase of hydrated IDPs, are not dominant in this particle. No magnetite rim is observed.

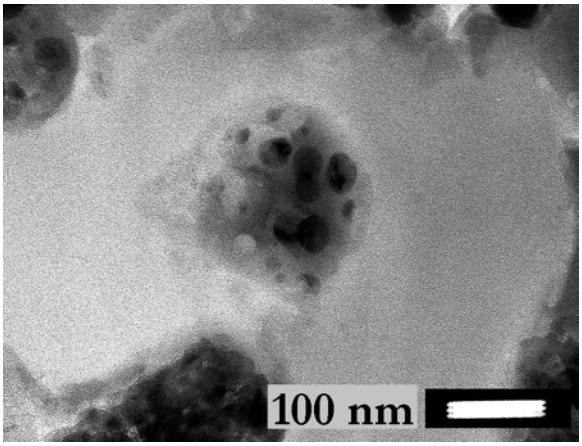

Figure 1: GEMS grains in IDP L2005 K7.

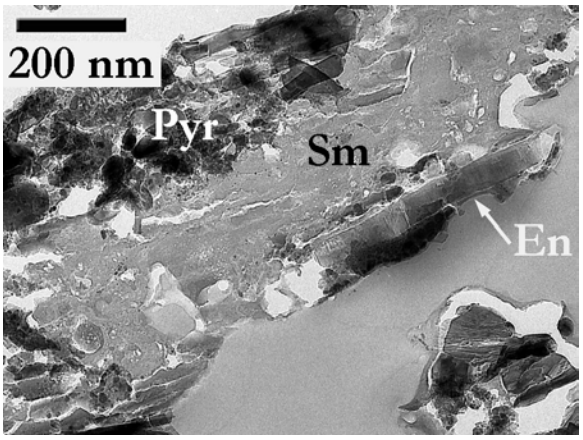

Figure 2: Smectite (Sm) adjacent to an enstatite (En) platelet and pyrrhotite (Pyr).

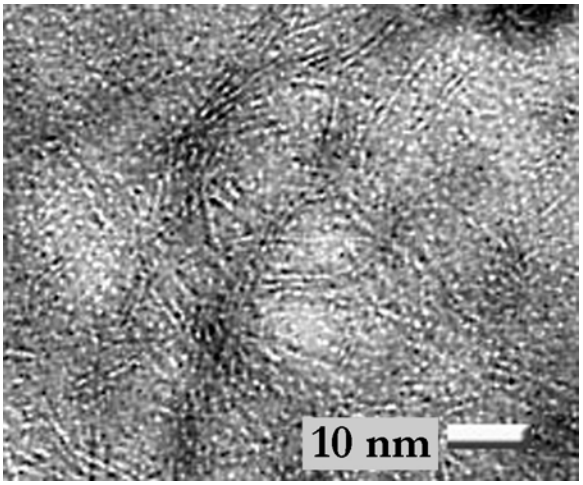

Figure 3: High resolution TEM image of smectite showing 14 Å (001) basal spacing.

Isotopic imaging: Both of the sections studied had C and O isotopic compositions that fell within the range of solar system materials. Given the area imaged, we estimate an upper limit on the abundance of stardust in this IDP of ~2,000 ppm. Both sections exhibited modest ^{15}N enrichments throughout, ranging from +100 to 200 per mil. However, several small (200 – 300 nm) ^{15}N-rich hotspots were observed in both sections, with values ranging from +400 to +900 ‰. This strongly heterogeneous N isotopic distribution indicates that the particle has experienced minimal parent body processing.

Discussion: The chemical, mineralogical, and isotopic features of most (~95 %) of this IDP are typical of CP IDPs. The anhydrous materials are mainly GEMS grains and enstatite (including rare platelets). GEMS grains are a major component of anhydrous IDPs that have not been observed in meteorites. Their physical characteristics show marked similarities to contemporary interstellar dust [10,11]. Enstatite whiskers and platelets are believed to be primary vapor phase condensates that formed in early solar nebula [12]. The presence of highly localized (200 nm) ^{15}N-rich 'hotspots' of probable presolar origin further indicate that this IDP is very primitive.

However, the IDP also contains a minor (~5%) amount of smectite clasts. Well developed smectite matrix has been observed in CI chondrites [13, 14]. By comparison, the smectite observed in this IDP is poorly crystallized, indicating non-optimal conditions for aqueous alteration, such as improper pH, minimal fluid, or low temperature. The wide basal spacing of the smectite suggests that the particle has not been heated to more than 600 °C [15]. This is supported by the lack of a well-developed magnetite rim on the particle.

Overall, the mineralogical and isotopic characteristics of IDP L2005K7 are similar to CP-type cometary IDPs. The presence of hydrous minerals in this particle are thus surprising. Two possible origins for this IDP should be considered: (1) anhydrous, primitive asteroidal material not represented in the meteorite collections, or (2) short-period comet that experienced a brief and incomplete aqueous alteration episode. The NASA Stardust spacecraft will soon return direct samples of comet Wild 2. These materials should be closely investigated for signs of aqueous processing.

References: [1] Brownlee D.E., (1978) *In Protostars & Planets*. (Gehrels T. ed) Univ. Arizona Press, 134-150. [2] Schramm L.S., Brownlee D.E. & Wheelock M.M. (1989) *Meteoritics* **24**, 99-112 [3] Mackinnon I.D.R. & Rietmeijer F.J.M. (1987) *Reviews Geophys.* **25**, 1527-1553 [4] Sandford S.A. & Walker R.M. (1985) *ApJ* **291**, 838-851 [5] Bradley J.P. & Brownlee D.E. (1986) Science 231, 1542-1544 [6] Bradley J.P. et al. (1996) *MAPS* **31**, 394-402 [7] Zolensky M.E. & Lindstrom D.J. (1992) *Proc. LPSC* **22**, 161-169 [8] Gibson E.K.Jr. & Bustin R. (1994) *AIP Proc.* **310**, 173 [9] Zolensky & Thomas K.L. (1995) *GCA* **59**, 4707-4712 [10] Bradley J.P. (1994) *Science* **265**, 925-929 [11] Bradley J.P. et al. (1999) *Science* **285**, 1716-1718 [12] Bradley J.P., Brownlee D.E. & Veblen D.R. (1983) *Nature* **301**, 473-477 [13] Tomeoka K & Buseck P.R. (1988) **GCA** 52, 1627-1640 [14] Zolensky et al. (2002) *MAPS* **37**, 737-761.[15] Nozaki W., Nakamura T. & Noguchi T. (2002) *Antarctic Meteorites* **XXVII**, 132-133.