

D-RICH WATER IN INTERPLANETARY DUST PARTICLES. S. Mukhopadhyay and L. R. Nittler, Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd. NW, Washington, DC 20015; email: sujoy@dtm.ciw.edu, lrn@dtm.ciw.edu.

Introduction: Hydrogen isotopic compositions in interplanetary dust particles (IDPs), in the form of D enrichments, provide unequivocal evidence for the survival of presolar organic matter (e.g., [1-4]). D/H enrichments of up to 50,000‰ have been reported from IDPs and such extreme values are presumably produced by ion-molecule reactions at 10-50 K in molecular clouds [1]. Although the phase(s) carrying the D enrichments remain unclear, it is generally accepted that the D excesses are associated with organic matter [1-5], while the phyllosilicates (the other host of phase for H in IDPs) do not seem to be anomalous in their H isotopic composition [4]. However, D enrichments in phyllosilicates have been reported from the Semarkona and Renazzo meteorites [6]. The primary goal of this work is to investigate H isotopic heterogeneity in IDPs and understand the chemistry and mineralogy of the phases carrying the D excesses. The current work extends the previous work done on characterizing H isotopic variability in IDPs [e.g., 1-5] and here we report the first clear evidence for a D-rich phase in IDPs that is not associated with organic matter.

Analytical Details: Three cluster IDPs were mounted on a clean gold foil and then pressed into the substrate using a sapphire disc. Using the 6f ion microprobe at the Carnegie Institution, ion images were acquired using a Cs^+ primary beam, focused to $<1 \mu\text{m}$ spot at 10 pA and 10 keV. The analyses were carried out in two steps. In the first step images of H^- , D^- , $^{12}\text{C}^-$, were acquired at low mass resolution with counting times of 10, 70, and 5 seconds respectively for each image. In the second step elemental maps of C^- , O^- , CN^- , Si^- , and $^{32}\text{S}^-$ were obtained at a mass resolution of 1600 (sufficient to separate $^{32}\text{S}^-$ from O_2^-). Counting times were 5, 1, 5, 10, and 5 seconds respectively for each image. Image processing software [3] was used to extract quantitative isotopic ratios on spatial scales of $\sim 1 \mu\text{m}$ or larger. C/H ratios in the IDPs were calculated by determining the C^-/H^- ion yields from measurements of C/H ratio of macromolecular organic matter in the Murchison meteorite (MMOM). The error on the C/H ratio is $\sim 25\%$, based on reproducibility of the MMOM C/H ratio, similar to the uncertainty reported from ion probe measurements on organic matter from the Orgueil meteorite [6].

Results and discussion: The IDPs exhibit large variations in δD both within a particle and between the different particles. The largest variation within a particle (L2036V6) is from -178‰ to $\sim 11500\text{‰}$ with the

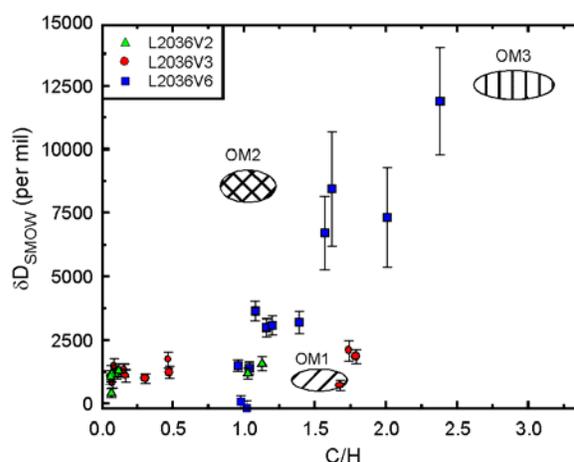


Figure 1: δD as a function of C/H ratios in different regions (ROIs) from 3 different cluster IDPs. The error bars on the H isotopic composition reflect both counting statistics errors as well as the reproducibility of standards. For clarity, the error bars on the C/H ratios ($\sim 25\%$) have not been shown. OM1, OM2, and OM3 are the end-member compositions of the organic matter as identified by Aléon et al. [4].

highest D enrichment occurring in an $\sim 1 \times 1 \mu\text{m}$ hot-spot. Such large variations within a single particle have been previously observed [1,4].

Figure 1 shows the H isotopic composition as a function of the C/H ratios in the IDPs. Most of the data points can be explained by mixing between the previously identified OM1, OM2, and OM3 components [4]. However, two of the IDPs (L2036V2 and L2036V3) have regions with low C/H ratios but D/H ratios of up to 1300‰ , which is significantly higher than previously reported values for carbon depleted regions in IDPs and distinct from terrestrial and chondritic water.

The C^- and D^- ion images for L2036V3 are shown in Figure 2. It is clear that a D hot-spot occurs in a region where the C counts are at background levels. Elemental maps obtained on the ion probe indicate the region to be O-rich but Si-depleted. High-resolution ($\sim 250 \text{ nm}$) X-ray mapping by a field emission SEM indicates that the D-hotspot is Si and C depleted, but rich in Mg and O.

From the above discussions and Figures 1 and 2 it is clear that in two of the IDPs, inorganic phases carry a heavy water signature. This is, to our knowledge, the

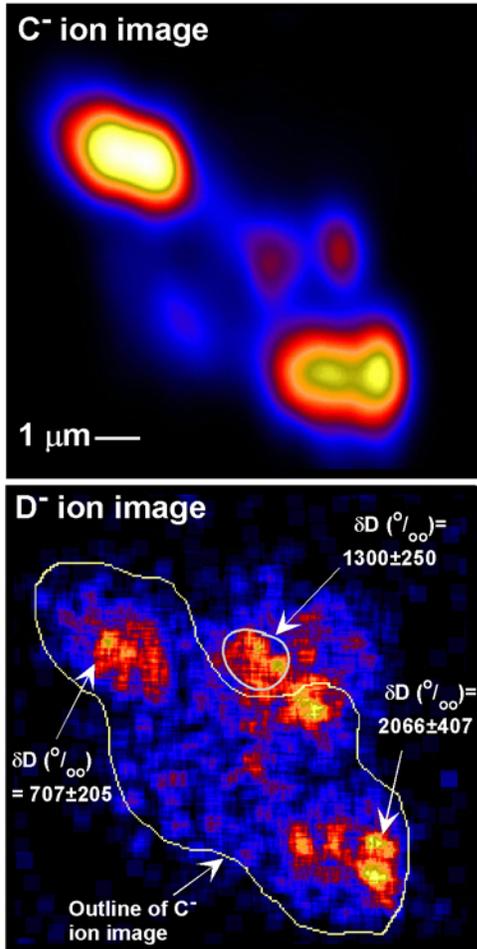
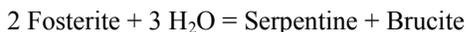


Figure 2: C and D ion images of L2036V3. Note the D hotspot in a region that is devoid of carbon. Two other D hotspots with δD of 707‰ and 2066‰ respectively, are associated with carbon rich regions. L2036V3, thus, has clear evidence of high D/H ratios in both organic and inorganic phases.

first positive identification of high D/H ratios in an inorganic phase in IDPs. While we plan to carry out TEM investigations to conclusively determine the mineralogy of the phase, currently our best estimate is that the heavy water signature in L2036V3 is carried by the mineral brucite [$\text{Mg}(\text{OH})_2$]. Brucite can be produced by the hydration of silicate phases through reactions such as:



If the D/H ratio of the water is high, the OH^- anion in brucite will keep a memory of this heavy water. The formation of brucite by the above reaction is kinetically inhibited in the solar nebula and, thus, aqueous alteration within a parent body is the favored explanation [e.g., 7]. However, recent modeling of the hydra-

tion reaction triggered by an adiabatic shock wave in an icy region of the nebula indicates that 1- μm sized grains can be hydrated within the lifetime of the nebula [8].

The D/H ratio of water in the IDPs we investigated is $\geq 1000\text{‰}$. Such values are not likely to be generated by equilibrium isotopic exchange between $\text{HD}(g)$ and $\text{H}_2\text{O}(g)$ followed by ice condensation, since the exchange kinetics at low temperatures ($<150\text{K}$) is too slow compared to the lifetime of the solar nebula [9]. The δD values might reflect incorporation of pristine interstellar water since our reported values are similar to the D/H ratios for water in the hot cores of molecular clouds [10-11]. For this idea to work, the ices on infalling grains cannot be vaporized. However, recent models indicate that a significant fraction of the infalling ice is likely to have been vaporized [12]. Alternatively, the high D/H ratio of the water could reflect D exchange between low δD water and high δD organic matter. Whatever the precise cause of the D enrichment of the water, it seems likely that the aqueous fluid from which the brucite formed had a significantly higher D/H ratio compared to terrestrial water.

Our reported δD value for water in the IDP L2036V3 and L2036V2 is similar to values reported from the Oort cloud comets, Halley, Hale Bopp, and Hyakutake, but unlike the water composition of most carbonaceous chondrites. However, the phyllosilicates in the LL3 chondrite Semarkona and the CR chondrite Renazzo also have high D/H ratios [6]. Hence, our new data suggests a possible link between Oort cloud comets, some chondrites, and the IDPs L2036V3 and L2036V2.

References: [1] Messenger S. (2000) *Nature*, 404, 968-971. [2] Stadermann F. J. (2001) *LPS XXXII*, Abstract # 1792. [3] Nittler L. R. and Messenger S. (1998) *LPS XXIX*, Abstract #1380. [4] Aléon J., et al. (2001) *GCA*, 65, 4399-4412. [5] Keller L., et al. (2002) *LPS XXXIII*, Abstract # 1869. [6] Deloule E. and Robert F. (1994) *GCA*, 59, 4695-4706. [7] Prinn R. J. and Fegley B. Jr. (1989) In *Origin & Evolution of Planetary & Satellite Atmospheres*, 78-136. [8] Ciesla F. J. et al. (2002) *Meteorit. Planet. Sci.*, 37(7), A34-A34. [9] Lécluse C. and Robert F. (1994) *GCA*, 58, 2927-2939. [10] Irvine W. M. et al., (2000) In *Protostars and Planets IV*, 1159-1200. [11] Gensheimer P. D. et al. (1996) *Astron. Astrophys.*, 314, 281-294. [12] Cassen P. and Chick K. M. (1997) In *Astrophysical Implications of the Laboratory Study of Presolar Materials*, 697-719.