

PRECISION OXYGEN ISOTOPE MEASUREMENTS OF TWO C-RICH HYDRATED INTERPLANETARY DUST PARTICLES.

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Introduction: Chondritic-smooth IDPs are low porosity objects whose mineralogy is dominated by aqueous alteration products such as Mg-rich phyllosilicates (smectite and serpentine group) and Mg-Fe carbonate minerals. Their hydrated mineralogy combined with low atmospheric entry velocities have been used to infer an origin largely from asteroidal sources. Spectroscopic studies show that the types and abundance of organic matter in CS IDPs is similar to that in CP IDPs [1]. Although CS IDPs show broad similarities to primitive carbonaceous chondrites, only a few particles have been directly linked to specific meteorite groups such as CM and CI chondrites based on the presence of diagnostic minerals [2]. Many CS IDPs however, have carbon contents that greatly exceed that of known meteorite groups suggesting that they either may derive from comets or represent samples of more primitive parent bodies than do meteorites [3-5]. It is now recognized that many large, dark primitive asteroids in the outer main belt, as well as some trans-Neptunian objects, show spectroscopic evidence for aqueous alteration products on their surfaces [6]. Some CS IDPs exhibit large bulk D enrichments similar to those observed in the cometary CP IDPs [7]. While hydrated minerals in comets have not been unambiguously identified to date, the presence of the smectite group mineral nontronite has been inferred from infrared spectra obtained from the ejecta from comet 9P/Tempel 1 during the Deep Impact mission [8]. Recent observations of low temperature sulfide minerals in Stardust mission samples suggest that limited aqueous activity occurred on comet Wild-2 [9]. All of these observations, taken together, suggest that the high-carbon hydrated IDPs are abundant and important samples of primitive solar system objects not represented in meteorite collections.

Oxygen isotopic compositions of chondrites reflect mixing between a ¹⁶O-rich reservoir and a ¹⁷O,¹⁸O-rich reservoir produced via mass-independent fractionation. The composition of the ¹⁶O-rich reservoir is well constrained [10] but material representing the ¹⁷O,¹⁸O-rich end-member is rare [11]. Self-shielding models predict that cometary water, presumed to represent this reservoir, should be enriched in ¹⁷O and ¹⁸O by > 200% [12]. The high-carbon hydrated IDPs may be among the best materials available to search for preserved “cometary” H₂O signatures. In order to better understand the origin and evolution of these particles,

we have obtained 10 hydrated interplanetary dust particles for coordinated mineralogical, isotopic and organic analyses. We have previously reported the results of mineralogical and O isotopic measurements of two hydrated IDPs [5]; here we present results of O isotopic measurements of three additional IDPs.

Samples and Methods: Three interplanetary dust particles (L2079C35, L2083D46 and L2083E46) were embedded in S and partially ultramicrotomed into ~70nm sections for analysis via transmission electron microscopy (TEM). The remainders of the unsliced particles were removed from S and pressed into high purity Au foil that was cleaned with HF acid and annealed at 800 degrees C. The pressed IDPs were analyzed via electron microprobe analysis (EPMA) for quantitative bulk chemical analysis.

After EPMA analysis, the IDPs were subjected to precision O isotope analysis with the UCLA Cameca IMS-1270 ion probe. A 20keV, 0.5nA Cs⁺ primary beam of ~15μm diameter was used for each measurement. Small particles of San Carlos olivine and Burma spinel were pressed into the Au foil for use as standards to correct for instrumental mass fractionation. The detection system was configured for multicollection, with ¹⁶O measured on a Faraday cup, and ¹⁷O and ¹⁸O measured on electron multipliers (EMs). Individual analyses consisted of 15 cycles of 10 seconds per cycle. Additionally, two microtome thin sections were measured for H isotopic compositions with the JSC NanoSIMS 50L ion probe. An 8 pA, 16 keV Cs⁺ primary beam was used. Measurements consisted of H, C, ¹²C, ¹⁶O, and ¹⁸O collected with EMs in multicollection. Terrestrial biotite and kerogen were used for isotopic standards.

A significant challenge in O isotope measurement of hydrated minerals is the interference from ¹⁶OH at mass ¹⁷O. We ensured that the ¹⁷O and ¹⁶OH peaks were fully resolved by using a mass resolution of >7000 and by careful analyses of San Carlos olivine, Burma spinel and chlorite hydrated mineral standards. The hydride was further suppressed with a cold finger attached to an LN2 dewar to trap volatiles in the sample chamber.

All sputtered ions were counted (i.e. presputtering was not used); after applying background, yield and deadtime corrections, we performed a change-point analysis on our data via R [13,14] in order to determine

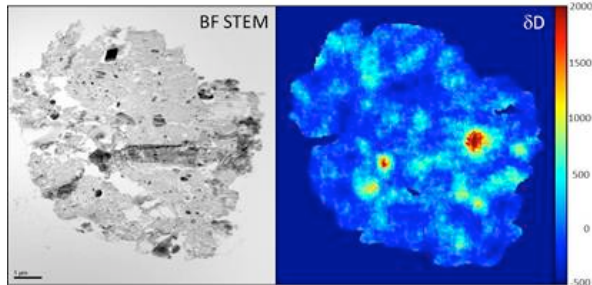


Figure 1: Brightfield STEM image of a thin section of C-rich hydrated IDP L2079C35 and its corresponding D/H image showing D hotspots that coincide with organic nanoglobules.

when the sample reached sputtering equilibrium; data points collected prior to the change point were excluded. Change-point analysis was also used to determine whether the IDP had completely sputtered.

Results: Mineralogy. IDPs C35 and E46 exhibited hydrated mineralogies, Fe-Ni sulfide grains, nanoglobules and occasional enstatite grains distributed throughout a fine-grained Mg-Fe saponite matrix. C35 also contained breunnerite (Mg,Fe)CO₃; solar flare tracks were observed in enstatite, indicating minimal atmospheric entry heating. The mineralogy of D46 is dominated by a large FeS grain with a minor component of adhering silicate material. D46 was strongly heated during atmospheric entry as evidenced by a well-developed magnetite rim. EPMA analyses show that both C35 and E46 have high carbon contents of 20 wt.% (~6X CI). D46 contains ~6 wt.% C. A significant amount of the carbon is present as carbon nanoglobules [15].

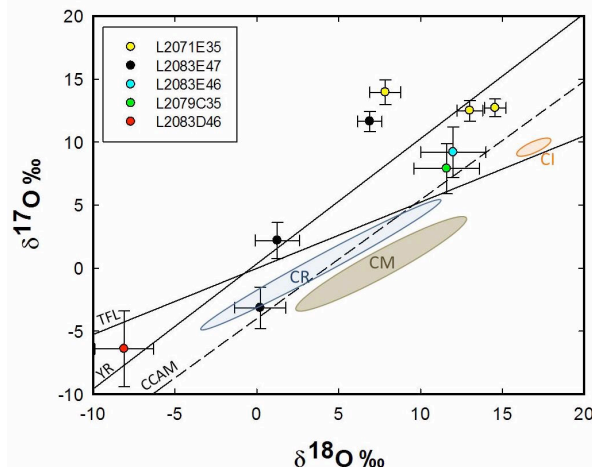


Figure 2: Oxygen isotope compositions for L2079C35, L2083D46 and L2083E46. Also plotted are data for L2071E35 and L2083E47 from [5]. Errors are 2 s.e.

Results: Hydrogen isotopes: Although the bulk δD values of both sections of L2079C35 were within error of SMOW (-33 ± 19 ‰, 1 ± 14 ‰ 1σ), sever-

al δD-rich hotspots were also identified, reaching 2000 ‰. As shown in Fig. 1, these hotspots are clearly associated with discrete carbonaceous inclusions that are akin to nanoglobules found in many meteorites and other IDPs [15].

Oxygen Isotopes. Results of the oxygen isotope measurements are shown in Figure 1. The oxygen isotope composition for L2079C35 was $\delta^{18}\text{O} = +11.6 \pm 1.9$ ‰, $\delta^{17}\text{O} = +7.9 \pm 1.9$ ‰ (2 s.e). The oxygen isotope composition for L2083D46 was $\delta^{18}\text{O} = -8.1 \pm 1.9$ ‰, $\delta^{17}\text{O} = -6.4 \pm 3.1$ ‰ (2 s.e). The oxygen isotope composition for L2083E46 was $\delta^{18}\text{O} = +12.0 \pm 1.9$ ‰, $\delta^{17}\text{O} = +9.2 \pm 2.0$ ‰ (2 s.e).

Discussion: Despite mineralogical similarities to highly aqueously altered carbonaceous chondrites, the hydrated IDPs we analyzed have oxygen isotopic compositions that are distinct from matrix materials in the CI, CM, and CR chondrites (Fig. 1). The IDPs plot along the Young-Russell line, with $\Delta^{17}\text{O}$ values for C35 and E46 suggestive of interaction with a ¹⁶O-poor reservoir. However, we have thus far not observed evidence of extreme ¹⁶O-poor reservoirs expected from self-shielding models and observed in Acfer 094 simplectite [11]. The high carbon contents of the IDPs also set them apart from known meteoritic samples. The lack of atmospheric entry heating effects are consistent with low encounter velocities and suggest either an asteroidal source, or a low inclination, low eccentricity cometary origin.

Conclusions: The unusual oxygen isotopic compositions, high carbon contents, and the abundance of D-rich nanoglobules, together, suggest that the high-carbon, hydrated IDPs are derived from a primitive source that is not yet represented in meteorite collections.

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