MINERALOGICAL STUDY OF HYDRATED IDPs: X-RAY DIFFRACTION AND TRANSMISSION ELECTRON MICROSCOPY.

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Introduction: Chondritic hydrated interplanetary dust particles (IDPs) comprise up to 50% of all IDPs collected in the stratosphere [1]. Hydrated IDPs are generally believed to be derived from asteroidal sources that have undergone aqueous alteration. However, the high C contents of hydrated IDPs (by 2 to 6X CI levels [2,3]) indicate that they are probably not derived from the same parent bodies sampled by the known chondritic meteorites. Some hydrated IDPs exhibit large deuterium enrichments [4] similar to those observed in anhydrous IDPs. Both anhydrous and hydrated IDPs contain a variety of anhydrous minerals such as silicates, sulfides, oxides, and carbonates. Controversies on hydrated IDPs still exist regarding their formation, history, and relationship to other primitive solar system materials, because of the lack of a systematic series of analysis on individual hydrated IDPs. In this study, we combine our observations of the bulk mineralogy, mineral/organic chemistry in order to derive a more complete picture of hydrated IDPs.

Samples and Methods: The strong depletion in Ca [1] has been used as a diagnostic feature of hydrated IDPs. The bulk mineralogy of 5 IDPs was investigated using synchrotron radiation X-ray diffraction method (SXRD). For the SXRD analysis, individual IDP samples were mounted on thin glass fibers (3 µm in diameter) and exposed to Cr Ka X-ray in a Gandolfi camera with an exposure duration up to 8 hours. SXRD has been demonstrated to be a non-destructive technique for hydrated extraterrestrial [5,6], therefore the samples studied here by SXDF are available for subsequent measurements.

Four of these IDPs and six additional hydrated IDPs with apparent diameters of 15 – 48 µm have been observed using a transmission electron microscope (TEM) equipped with an energy-dispersive X-ray detector (EDX). Since all of our samples were embedded in elemental sulfur and thin-sectioned using an ultramicrotome, additional information of organic matter in the individual specimen is available with techniques such as Fourier transform infrared (FTIR) microspectroscopy and Carbon X-ray absorption near edge structure (C-XANES) spectroscopy.

Results: *Phyllosilicates* are identified using several criteria: 1) electron diffraction and SXRD analyses (Fig.1), 2) flaky to fine-grained morphologies observed in TEM images and characteristic basal fringe spacings, and 3) appropriate chemical composition (Fig.2).

Smectite in hydrated IDPs is typically poorly crystalline (<50 nm in diameter). The observed molar Fe/(Fe+Mg) ratio of the smectite varies from 0.28 to 0.52. Smectite in *L2011Q9* contains aligned Fe-oxide grains (~20nm) with minor amounts of Si, Ni and S (Fig.3). The electron diffraction patterns are consistent with ferrihydrite. SXRD analysis of *L2036E23* shows (001) basal reflection of smectite at 8º and broad serpentine reflection near 18º. The peak width of the basal reflection indicates that serpentine in L2036E23 has variable spacing. TEM observation reveals that this particle exhibits a distinctive fine-scale intergrowth of smectite and serpentine. IDP L2006A5 shows a fine grained compact texture: sharp reflections of anhydrous silicates; olivine and pyroxene, and phyllosilicates; (001) basal reflections of serpentine and tochilinite are observed in the X-ray diffraction pattern (Fig.1b). TEM observation of L2006A5 indicates that tochilinite occurs in one small area (<2.5µm) showing concentric structures as intimate intergrowths with a very Fe-rich serpentine, probably cronstedtite (Fig. 4). Olivines in L2006A5 range in composition from Fo80 to Fo100. Solar flare tracks are not recognized in either olivine or fassaite grains of L2006A5. GEMS (glass with embedded metal and sulfide [7]) which are commonly observed in anhydrous IDPs have not been observed yet in L2006A5. The glassy materials in our samples tend to be Fe-rich (Fig.2).

Carbonates: Siderite, breunnerite and magnesite that are observed by SXRD and TEM analysis. They occur as rhombohedral grains (< 200nm in diameter) and also rounded grains (10-150 nm). Other minerals observed in all of the samples include Fe-Ni sulfides (pyrrhotite and pentlandite), magnetite, and Fe-Ni metal.

Discussion: Hydrated IDPs show strong similarities to CI carbonaceous chondrites such as intergrowths of smectite and serpentine, and ferrihydrite in smectite [8,9]. However, the chemical composition of smectite in these hydrated IDPs are richer in iron compared with those from CI carbonaceous chondrites matrices, but similar to those in the Tagish Lake carbonaceous chondrite matrix [10] and hydrated Antarctic micrometeorites [6](Fig.2). It should be noted that size of our particles are 2-3 times larger than typical IDPs, and are similar in size to smaller Antarctic micrometeorites. Magnesiowüstite, which is a characteristic mineral in Antarctic micrometeorites, is not observed in our samples. Characteristic features of SXRD from CI chondrites are that 1) 001 basal reflections of smectite and serpentine show similar intensity and 2) reflections of magnetite are strong and sharp [11]. These same features are observed in SXRD from hydrated IDPs.

L2006A5 is a tochilinite-cronstedtite-bearing particle similar to other rare hydrated IDPs that have been linked directly to CM carbonaceous chondrites [e.g.12]. SXRD is very powerful non-destructive technique to detect minor amounts of minerals in sub-micron size extraterrestrial samples that should be suitable for fine-grained samples of future sample return missions, STARDUST and Hayabusa.

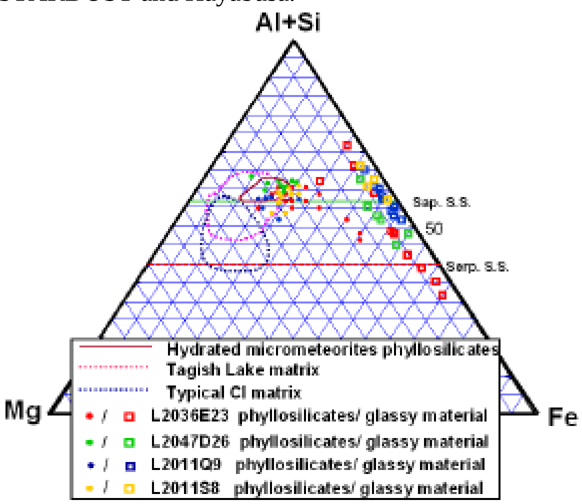

Fig.2: (Si+Al)-Mg-Fe atomic ratio ternary diagram of the chemical compositions of smectite and glassy material from 4 IDPs and fields of smectite from carbonaceous chondrites matrices and 3 hydrated Antarctic micrometeorites [6].

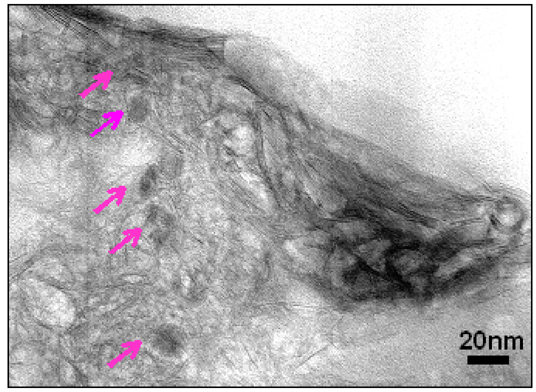

Fig.3: TEM image of smectite with entangled structure in hydrated IDP L2011Q9. Aligned ferrihydrite grains ~20nm in diameter (arrowed) are associated in smectite.

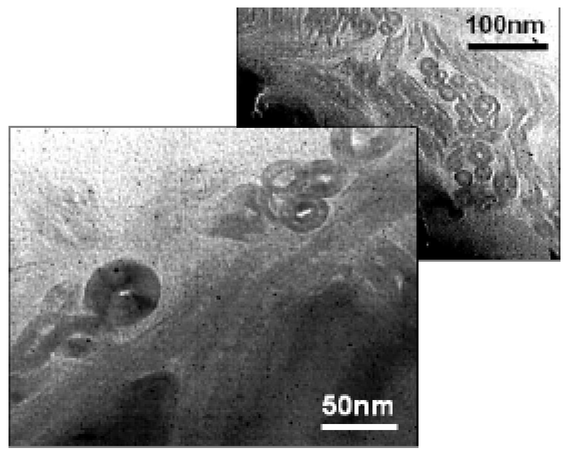

Fig.4: TEM images of tochilinite-rich region in L2006A5.

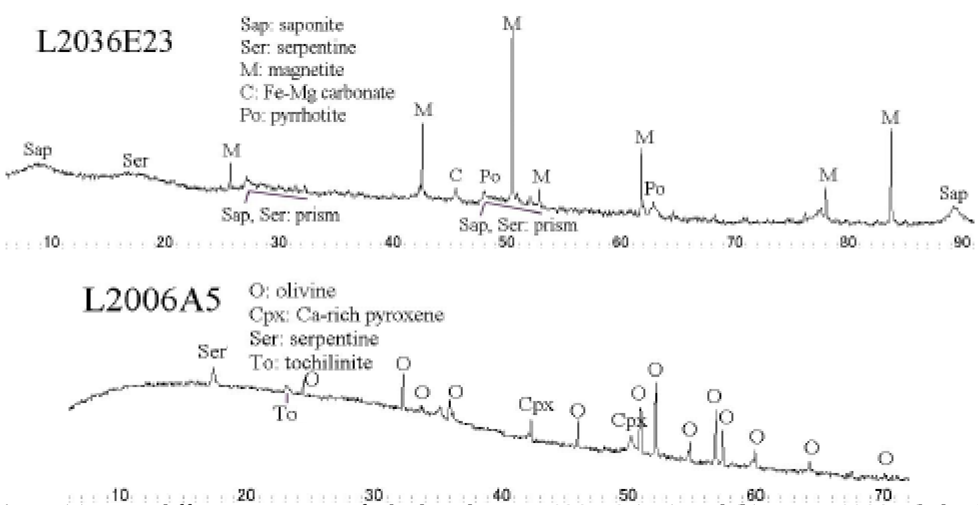

Fig. 1: (a) X-ray diffraction patterns of a hydrated IDP L2036E23 (top), and **(b)** IDP L2006A5 (below).

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