

ANALYSIS OF FLUID INCLUSIONS IN ASTROMATERIALS: WHY, WHERE AND HOW.

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Why: Aqueous fluid inclusions in meteorites and other astromaterials can provide fundamental information related to the location and timing of aqueous alteration in the solar system, and the detailed nature of the aqueous fluids themselves [1,2]. Microanalytical techniques are finally at the level where such studies are possible.

Where: The best known extraterrestrial fluid inclusions are found within xenolithic halite/sylvite crystals in the H chondrite regolith breccias Monahans (1998) (H5) and Zag (H3-6) [3,4], which are associated with halite-bearing C1 material [5]. CO₂ bearing aqueous fluid inclusions have recently been described from calcite in the Sutter's Mill CM chondrite [6]. We have also identified a potential fluid inclusion in Sutter's Mill sphalerite. It can be assumed that additional, diminutive fluid inclusions can be found in chondrites in such secondary phases as halides, carbonates, oxides (mainly magnetite), sulfides, and phosphates. Roedder reported fluid inclusions in apatite/whitlockite in Jilin [H5] many years ago [7], a report that has not been disproved, but also not verified.

The report of fluid inclusions in Jilin should be investigated. Unfortunately, the phosphate crystals that were examined at that time were subsequently consumed during a chronological investigation, but it should be straightforward to repeat that examination. If verified, this would establish phosphates as a significant target in other meteorites, especially CI chondrites. Sutter's Mill is an obvious target for further searches for fluid inclusions in carbonaceous chondrites, as well as the recent Tarda, Aguas Zarcas, and Flensburg C1/2 chondrite falls and the C1/2 carbonaceous chondrite stones in Almahata Sitta. Fluid inclusions should be sought among the samples returned from C-complex asteroids Ryugu and Bennu.

Martian rocks have been found to contain fluid inclusions, including olivine and augite crystals in Lafayette (nakhlite) [8] and pyroxene in Allan Hills 84001 (Martian orthopyroxinite) [9]. Further such investigations of Martian rocks are warranted.

How: How does one locate and analyze fluid inclusions and minimize contamination concerns? Here are a few useful steps. (1) Do not use grains or thin sections that have been heated or analyzed in an e-beam instrument. Heating from these analyses will probably have decrepitated the inclusions. (2) Make new thin sections without use of fluids (or at least without water or oil) using falls that have not been washed or sawn using water or oil [1]. Even falls can be problematic. For example, most recovered stones of Tagish Lake, Bells and Sutter's Mill were collected after either rain or soaking in lake water [10-12]. Extreme caution must be taken when dealing with falls that can have been infiltrated by terrestrial fluids. (3) Freezing thin or polished sections and grains before petrographic observation can promote nucleation of vapor bubbles, making candidate inclusions more visible during optical microscopy. (4) Potential fluid inclusions can be located using X-ray computed micro-tomography (XRCT) or in the TEM [6]. These techniques are in fact necessary for opaque minerals such as oxides and sulfides. (5) Reflected light examination of highly-polished surfaces can reveal fluid inclusions as surface pits, frequently with crystallographically-oriented, euhedral outlines (see [12] fig. 4). These pits will also be evident in SEM-SEI images - although new thin sections will probably then have to be made for further investigation.

One reason that so few fluid inclusions have been reported in astromaterials is that they tend to be very small - generally too small for characterization by Raman microspectroscopy or LAB-ICPMS. We have recently successfully applied XRCT, TEM, SIMS (freezing stage) and TOF-SIMS (freezing stage) techniques to this endeavor [6,13,14]. TOF-SIMS is currently the most useful technique for measuring fluid bulk compositions.

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