# FLUID INCLUSIONS IN CARBONACEOUS CHONDRITES

Joel Saylor[1], Michael Zolensky[2], Robert Bodnar[3], Loan Le[4] and Craig Schwandt[4]
[1]Dept. of Geological Sciences, Case Western Reserve University, Cleveland, Ohio 44106 (jes26@cwru.edu); [2]NASA Johnson Space Center, Houston, Texas 77058; [3]Dept. of Geological Sciences, Virginia Tech, Blacksburg, VA 24061; [4]Lockheed Engineering and Science Co, Houston, Texas 77058.

**Introduction:** Fluid inclusions have been found in two H5 chondrites, Monahans (1998) and Zag [1], and represent the first direct samples of the asteroidal fluid that effected aqueous alteration. For the first time the possibility of doing direct work on this fluid, and thereby placing real constraints on asteroidal alteration processes, presents itself. In addition, this water presents the first possibility of tracing the origins of water on Earth and in our solar system. We reason that if fluid inclusions are present in fairly dry ordinary chondrites, surely they must be present in wet carbonaceous chondrites.

Our goals are to locate fluid inclusions in likely carbonaceous chondrites, characterize the minerals and lithologies where the fluid inclusions occur and, characterize the fluid inclusions themselves.

**Samples & Methods:** 19 different meteorites were studied: **CI1s**: Orgueil, Ivuna, Alais; **CM2s**: ALH 83100, Y82162, LON 94101, Cold Bokkeveld, ALH 84029, ALH 81002, Y86029, EET 90047, Bells, Kivesvaara, Sayama; **CM1**: EET 83334, **CV3s**: QUE 94546, Efremovka, Allende; and **Tagish Lake.** Moving vapor bubbles were considered concrete evidence of a fluid inclusion. We initially used existing thin sections to locate meteorites which displayed fluid inclusions. Subsequently, we made new, special thin sections by techniques optimized for fluid inclusion work, as described in [2], and to verify that the inclusions are not sample preparation artifacts.

A Cameca SX-100 microprobe was used to probe fluid inclusion-bearing and associated minerals (primarily olivines and carbonates) and to obtain BSE images of the thin sections.

**Results and Discussion:** Fluid inclusions were positively identified in 3 CM2s and 2 CI1s. In addition, the possibility of further inclusions remain for several other meteorites. The fluid inclusions, whose diameters measured less than 10 micrometers, occurred within several minerals. In LON 94101 these minerals were forsteritic olivine and Ca-carbonate. In ALH 84029 the fluid inclusions were found in both Ca and Ca/Mg carbonates. In Sayama they are in Ca-carbonates. Fluid inclusions in two CI chondrites, Ivuna and Orgueil have been briefly described in another abstract [3]. These were also found exclusively in Ca-carbonates.

The fluid inclusions that we found occur in a variety of lithologies, though in the same lithology within each meteorite. LON 94101 is an especially heterogeneous mixture of disparate CM2 lithologies; the fluid inclusion-bearing lithology consists of a dark matrix composed primarily fine-grained phyllosilicates and fine-grained sulfides. Coarser phyllosilicates are present, and occur primarily in altered amoeboid olivine inclusions or remnant chondrules. The primary transparent phase is olivine of widely varying texture. Secondary anhedral granular carbonates are also present, though they made up less than 5% by volume of the samples. A few rounded grains of metal and even fewer euhedral sulfide grains were seen in one sample.

In ALH 84029 the relative proportions of olivine and carbonate are almost reversed relative to LON 94101. It also contains more remnant chondrules and altered amoeboid olivine inclusions than the former meteorite. The remnant chondrules have largely been altered to phyllosilicates and carbonates. In one of the samples carbonate appears to be concentrated in, though not exclusive to, amoeboid inclusions and remnant chondrules. The matrix consists of an equal mixture of light-colored (sulfide poor) fine-grained phyllosilicates, some of which had a variolitic texture, and darker phyllosilicate material similar to that in LON 94101.

Sayama is described in another abstract in this volume [4]. Briefly, it is a newly recognized CM2 fall exhibiting extensive aqueous alteration. Carbonates are very abundant, and sometimes contain a very high density of what appear to be one-phase fluid inclusions (no bubble). Of the three CMs where we have seen fluid inclusions, it is the only fall; this is important since we can not at this time rule out terrestrial alteration for the formation of inclusions in the Antarctic CM finds. Sayama is proof that fluid inclusions are definitely preserved in at least some CM chondrites

We found no fluid inclusions in 9 other CM1 and CM2 chondrites. In addition to samples where aqueous alteration was prominent and where fluid inclusions were expected, we studied several CV3s, both falls and finds. In the 3 sections of CV3s that were studied no fluid inclusions were found.

**Discussion**: The fact that fluid inclusions were found in the same lithology in several samples of the same meteorites yet no samples of other meteorites argues strongly in favour of the fluid inclusions being of extraterrestrial origin. Contamination during preparation would affect all meteorites prepared in that fashion in the same way. To verify this, we have begun to make and examine new sections of the target meteorites, made using special techniques which include use of isopropyl alcohol as the only fluid, hand polishing and grinding, etc. As of the writing of this abstract we have located inclusions in new sections of Sayama and LON 94101, and just begun examining the new sections of the other meteorites. In this regard it is fair to say that a serious search for fluid inclusions can probably not be made on any other existing meteorite thin sections, because of the probability of contamination by sample preparation fluids [1]. The extraterrestrial origins of these fluid inclusions will be further tested by heating and freezing experiments to reveal whether they are the expected brines similar to those found in earlier chondrite fluid inclusions [1]. In addition, the Raman microprobe should prove definitive in identifying possible contamination, since we postulate that the fluids present are brines and the presence of peaks in the wavelengths associated with sample preparation alcohol would indicate contamination.

Several ideas have been put forward to explain why fluid inclusions would not be present in more of these highly-altered chondrites. They all center around the low hardness or brittleness of the potential fluid-bearing minerals, and their breakage upon even gentle impacts. In addition, we found that a large number of the fluid inclusions were destroyed upon microprobing – and how many existing thin sections of carbonaceous chondrites have escaped that fate?.

Despite the fact that ALH 84029 contains numerous fluid inclusions, a meteorite that was thought to be paired with it, ALH 83100, was found to be barren. Perhaps these meteorites are not paired after all.

**Conclusions:** 1) Fluid inclusions are present in carbonaceous chondrites. 2) Of the chondrites studied (CI1, CM1&2, CV3) fluid inclusions were found only in CM2s and CI1s, and by extrapolation are most likely to be found there in the future. 3) Fluid inclusions occur in at least two separate lithologies, yet these two lithologies are similar in the presence of olivines, the lack of metals or coarse-grained sulfides, the presence of amoeboid inclusions and remnant chondrules and the presence of at least some secondary carbonates. 4) Fluid inclusions were found in only three CM2 meteorites, all of which had been moderately to highly aqueously altered and not in any that were altered to a greater or lesser degree. There therefore seems to be a narrow range of conditions under which a meteorite will retain trapped fluid. 5) The fact that probing with a microprobe or, presumably any other particle beam and possibly simply any significant heating, decrepitates the inclusions may explain why so few inclusions have been found to date. 6) The fact that no fluid inclusions were found in ALH 83100 which is assumed to be paired with for ALH 84029 may indicate that in fact these two are not paired. 7) The fact that fluid inclusions were found in all species of carbonates in the meteorites where they were found is an indication that all of the species of carbonates, in at least these two meteorites and possibly with broader application, were asteroidal, rather than nebular, in origin.

**References:**

[1] Zolensky, M.E. et al. (1999) *Science* **285**, 1377-1379; [2] Bodnar, R.J. and Zolensky M. E. (2000) *Meteoritics & Planetary Sci.* **35**, A29-30; [3] Bodnar, R.J. and Zolensky M. E. (2000) *GSA Abstracts with Programs* **32**, A7; [4] Takaoka N. et al. (2001) *LPSC XXXII*, this volume.