Early Solar System Solids from Primitive Meteorites and a Comet

by Noriko Kita

Chondrules in primitive meteorites are ≤mm sized melted spherules that formed very early in the history of the solar system before the formation of planets (Fig.1). In the Department's WiscSIMS laboratory, we are studying the ratios of all three stable oxygen isotopes in chondrules from various classes of primitive meteorites, which reflect the heterogeneity of the early solar system and the process of gas-solid interactions (Fig. 2). Applying a new technique with an ultra-small beam spot (≤2μm) that he developed at UW, Takayuki Ushikubo and others have analyzed particles from the comet Wild 2 collected by the NASA Stardust Mission (Fig. 3). Our new comet data (Fig. 2) were quite a surprise and disprove conventional wisdom. Instead of volatile-rich ice from the outer reaches of the solar system where comets form, the data resemble chondrules from asteroids indicating that solid particles in the early solar system migrated widely from the asteroid belt (~3AU) to the outer solar system (≥30AU). Following this discovery that was published in *Science* (Nakamura et al. 2008), post-docs Daisuke Nakashima and Rudraswami Gowda joined our group in 2009 to study more comet particles and chondrules. In addition, we perform high precision short-lived nuclide chronology (Al-Mg) of meteorites. These results allow us to resolve events that are as little as 10,000 years apart that occurred 4,567 million years ago during the first few million years of solar system evolution. Scientists travel to Madison from around the world to collaborate in this research and use the WiscSIMS ion microprobe, including: Tomoki Nakamura (Kyushu University, Japan), Glenn MacPherson (Smithsonian Institute), Denton Ebel (American Museum of Natural History), Michael Weisberg (CUNY), and Frank Richter and Andrew Davis (University of Chicago). ●

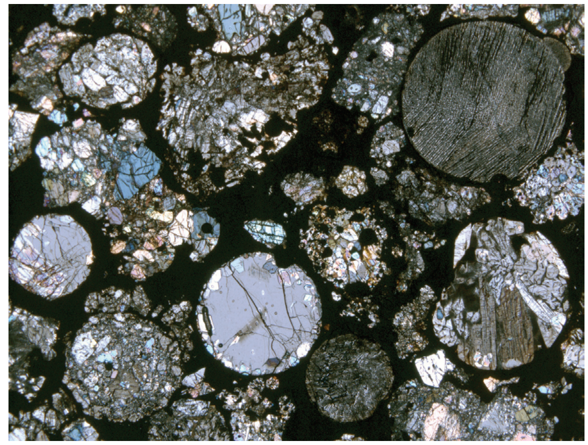


Figure 1. Chondrules from Semarkona, an ordinary chondritic meteorite (not Wild 2). F.O.V. ~ 5 mm.

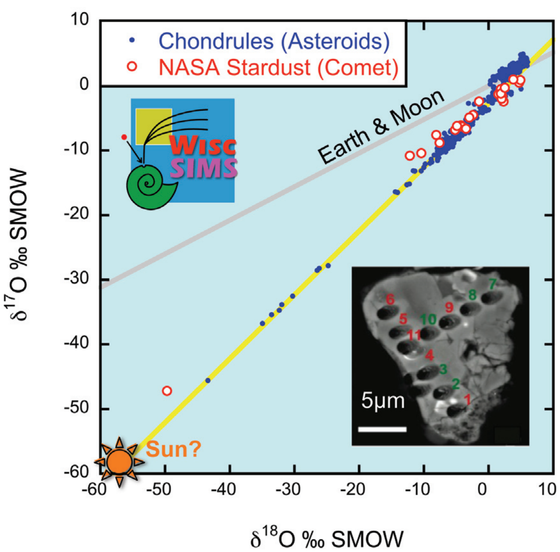


Figure 2. Oxygen three isotope plot for chondrules in meteorites (blue) and comet particles from NASA Stardust Mission (open red). Inserted picture is a scanning electron microscope image of a comet particle showing 2µm analysis pits for oxygen isotopes. Both chondrules and comet data plot on a slope ~1.0 line (yellow), indicating a wide range of variation at the beginning of the solar system. The estimated value for the sun according to the latest analysis of solar wind is shown at the lower left of the diagram (Nakamura et al. 2008).

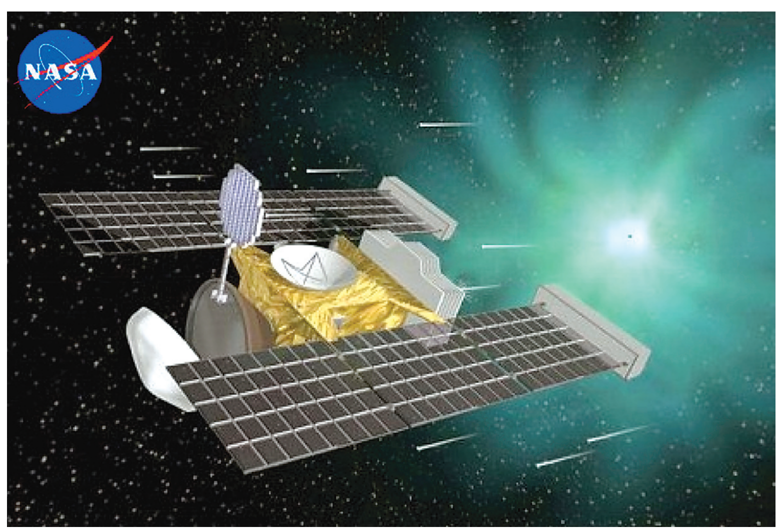


Figure 3. Image of the NASA Stardust spacecraft approaching comet Wild 2 to collect particles emitted from the comet. These particles were taken to Houston and some then came to Madison for analysis.

The Tale of Two Speleothems

by Ian Orland

Calcite speleothems (e.g. stalagmites and stalactites) provide an important geochemical record of past climate change. Similar to a cross-section of concentric tree rings, stalagmites precipitate calcite layers on their outer surface and thus preserve time-consecutive calcite growth. The calcite can be dated by U-series geochronology. Stable isotope and trace element analysis of speleothems can reveal changes in annual rainfall, monsoon strength, vegetation cover, or regional climate dynamics. The conventional technique for sampling a radial traverse of a speleothem is with a ~0.5 mm diameter dental-drill. The goal of ongoing research directed by Professor John Valley in the WiscSIMS lab is to use the high spatial resolution of the ion microprobe (~10 μm diameter spot), which translates to a higher temporal resolution of geochemical analyses, to identify and interpret a sub-annual/seasonal climate signal from oxygen isotopes ($\delta^{18}O$) in calcite speleothems (Figure 1).

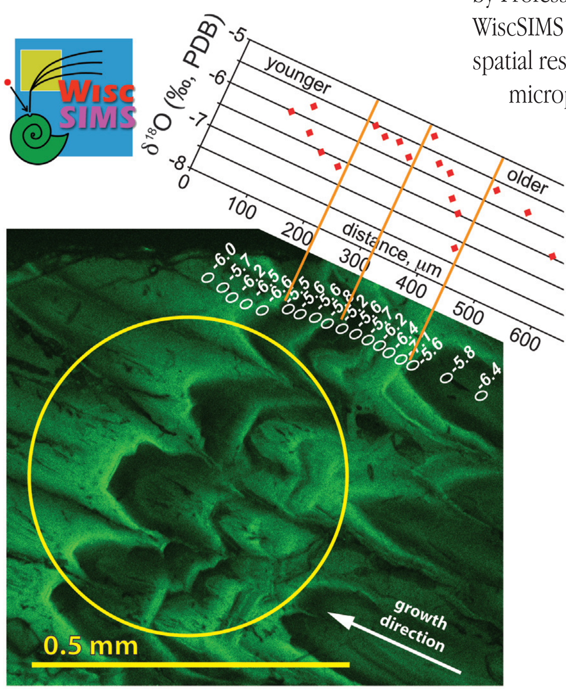


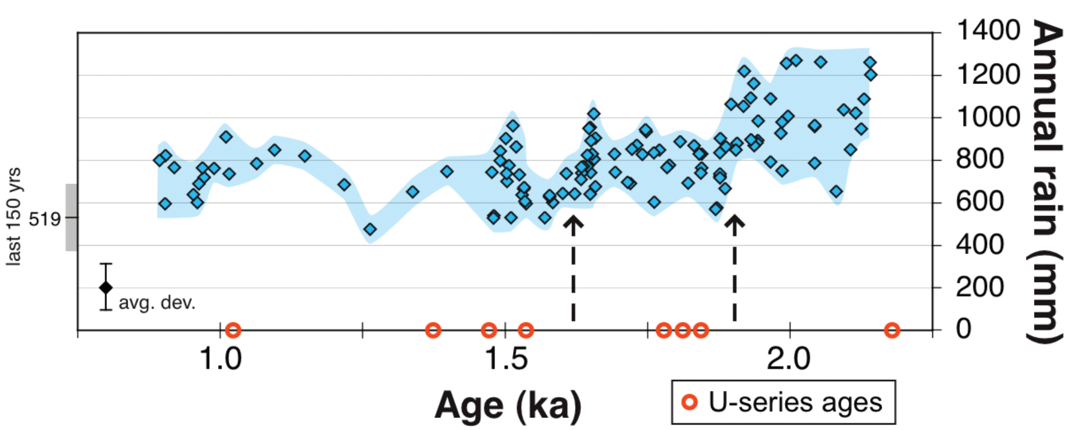
Figure 1. Luminescent image of four years of growth, ~1500 years ago, in a calcite stalagmite from Soreq cave. Green luminescence marks growth during the winter wet season and dark calcite grew during summer. Oxygen isotope ratios ($\delta^{18}O$ white circles) confirm seasonality, lower $\delta^{18}O$ correlates to higher annual rainfall. Note that previous studies at 0.5-mm scale (yellow circle) cannot resolve wet and dry seasons (Orland et al. 2007).

Collaboration between the Department of Geoscience and a group led by Dr. Mira Bar-Matthews at the Geological Survey of Israel has resulted in analysis of multiple samples from Soreq Cave, Israel, that grew over the last 25 ky. Imaging of annual growth bands in Soreq Cave speleothems by confocal laser fluorescence microscopy has enabled us to identify and analyze patterns of $\delta^{18}O$ variability within annual bands. Therefore, as well as examining the character of natural, rapid climate changes in the Eastern Mediterranean region since the last glacial maximum (LGM; 22 ky), this investigation has focused on interpreting changes in seasonality.

Figure 3. Ian Orland in Soreq Cave, Israel.

Published results from early work in this study (Orland et al., 2009, *Quaternary Research*) examine a Soreq sample that grew from 2.2-0.9 ky. Modern geochemical observations of meteoric waters, dripwaters, and general cave hydrology resulted in an annual-scale estimate of rainfall amount over the time period when the speleothem grew (see Figure 2). Interestingly, the timing of regional drying at ~1.7 ky coincides with the contraction of the Byzantine Empire out of the Levant region.

Currently, analysis is focused on seasonality variations as interpreted from $\delta^{18}O$ values and fluorescent annual bands in a sample that grew during the warming following the LGM. Successful collaboration is key to this research project; this has included a trip by graduate student Ian Orland to Israel in the summer of 2007 (Figure 3; trip supported by a BP-sponsored department grant for summer research) and a Bar-Matthews sabbatical to UW-Madison during the summer of 2009. ●



Left: Figure 2. Record of drying climate estimated from a stalagmite for the Eastern Mediterranean region (Orland et al. 2009).

To an Ocean of Fish from a Weeks Hall Laboratory

by C.S. Clay and John J. Magnuson

Who would study fish in a Geology and Geophysics department? We did! Starting in the 1980's, our Geology/Limnology group studied the scatter of underwater sound by fish to investigate fish populations and their distributions. Our graduates have spread these ideas worldwide.

In January 2008 an international meeting focused on modeling fish and zooplankton acoustic scattering at the University of Washington's Friday Harbor Laboratory. Five participants had Wisconsin connections (photo, right).

Participants at the 2008 "Workshop on modeling fish and zooplankton acoustic scattering" at the Friday Harbor Lab. Left to right: John Horne (guest scientist at UW in 1980's), Dezhang Chu (UW PhD 1989), C.S. Clay (UW emeritus professor), Michael Jech (UW PhD 1991), and Timothy Stanton (UW research scientist 1980-88).

Our research on the scatter of sound from fish began in the basement of Weeks Hall in the 1970's, funded by the Office of Naval Research. The principles of echo sounders and scattering by fishes were published in *Acoustical Oceanography* (Clay & Medwin 1977). At Columbia University, before moving to Madison, Clay had used vertical and side-scan echo sounders to map the sea floor and locate objects in the water. He was chief scientist during the sonar search that located the nuclear submarine Thresher in 2400 m of water (sunk April 1963 with a crew of 129).

At UW, our oceanographic trips off Cape Hatteras began in the late 1970's and continued into the 1990's. We worked at the edge of the Gulf Stream Front, initially on the shelf and then farther offshore. Our methods were crude by today's standards; we recorded the echoes digitally using three Apple II computers with 64K processors.

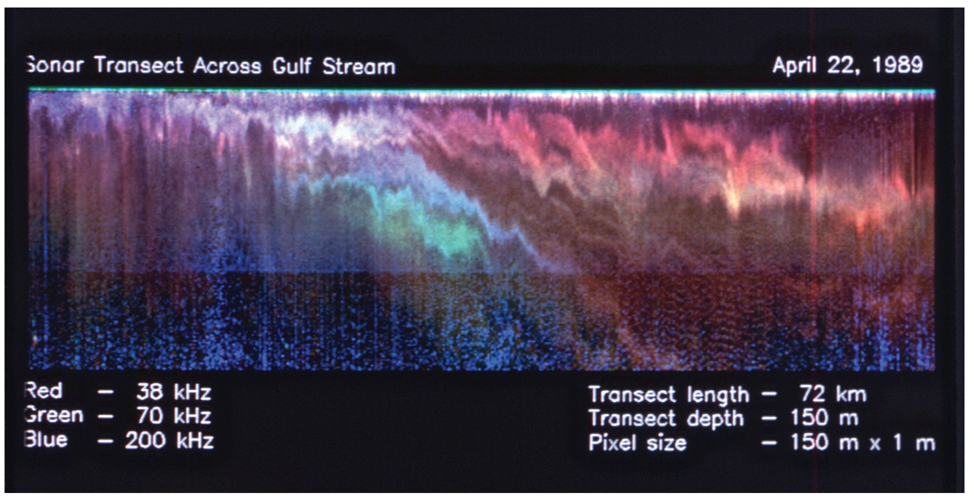


Figure 1. The sonar shows a vertical cross-section of marine animals at the Gulf Stream Front. The red backscatter on the right suggests these fish are large. Going to the left, the boundary red to blue-green is sharp and smaller marine animals are present.

Multi-frequency echo sounding systems (sonars) have been used for decades to study the sea floor and organisms in the water column. Echoes from low frequency sound (long wavelength, 38 kHz ~ 4 cm) reveal larger fish. High frequencies with shorter wavelengths (200 kHz ~ 0.75 cm) scatter sound waves from smaller animals (Fig. 1).

Underwater sound enables biological oceanographers to see fish and zooplankton distributions, abundances, and organism sizes in the water column at a fine spatial grain over large areas or extents. Questions about marine life can be asked and answered with the spatial detail and the broad extent familiar to terrestrial scientists working in the field of landscape ecology. With sonar we have been able to see and classify patches of organisms and we can examine the distribution of organisms in both the time/space domain and the frequency domain. Many UW students and colleagues, unnamed in this short piece, have contributed to the applications of underwater acoustics. Interdisciplinary efforts such as this provide new understanding, not possible alone, and generated a group of young scientists who can live in both worlds—acoustics and marine ecology.