

## SUTTER'S MILL METEORITE OXYGEN ISOTOPES: MORE EVIDENCE FOR WATER-ROCK OPEN SYSTEM ALTERATION I. E. Kohl<sup>1</sup>, Q. Z. Yin<sup>2</sup>, E. D. Young<sup>1</sup>

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**Introduction:** A recent research article in Science [1] highlighted the significance of Doppler radar enabled rapid recovery of meteorite fragments from a carbonaceous chondrite regolith breccia. The meteorite has been named Sutter's Mill (SM) and is composed of CM-type carbonaceous chondrite mixed with highly reduced xenolithic material. Mn-Cr chronometry suggests accretion of SM at 4566.57± 0.66 Myr before present.

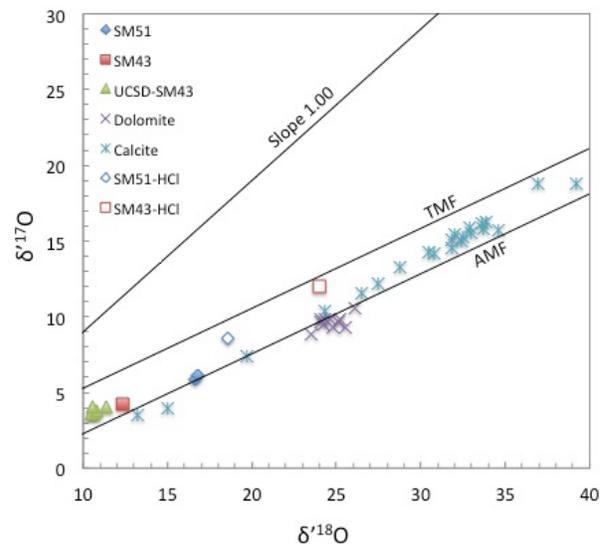
Oxygen isotope measurements show a wide range of values, as expected for a regolith breccia containing a variety of materials. Both primary phases and alteration products are present. The former consist of olivine and pyroxene while that latter is represented by a phyllosilicate matrix with abundant carbonate (calcite and dolomite).

We interpret these oxygen isotope data as indication that alteration products formed in an open system with fluid flow in the presence of a temperature gradient. This is consistent with carbonate data from CM meteorites in general, which also display alteration products along, or nearly along, a fractionation line with a relatively constant  $\Delta^{17}\text{O}$ . This study presents additional data points produced via laser fluorination of bulk samples (SM43) and 1M HCl-treated fragments (SM43 and SM51) of the SM meteorite. HCl treatment was employed in an attempt to remove some of the carbonate minerals from the bulk samples. The target of this treatment was the measurement of the unaltered residue.

**Materials and Methods:** Acid treated samples were treated with 1M HCl at 150 °C for 3 hours, washed 3x in DD water and dried for 36 hours at 60 °C. Samples were subsequently heated to 80 °C with an IR lamp while pumping on our vacuum line for 48 hours. Oxygen isotope analyses were performed by infrared laser-assisted fluorination following the general method modified for triple-oxygen isotope ratio analysis by [2]. Oxygen isotope ratios were measured on oxygen (as O<sub>2</sub> gas) extracted from the meteorite by heating with a 20 Watt CO<sub>2</sub> laser in the presence of purified F<sub>2</sub> gas. Liberated O<sub>2</sub> was separated from residual F<sub>2</sub> by reaction of the latter over hot KBr and cryogenic trapping of Br<sub>2</sub> gas, then trapped onto molecular sieve 13X at -196 °C. Ubiquitous trace amounts of NF<sub>3</sub> cause <sup>17</sup>O<sup>16</sup>O interferences (at mass/charge = 33) due to NF produced in the source of the mass spectrometer. Trace NF<sub>3</sub> was removed by distilling the

oxygen from the 13X molecular sieve at -130 °C to a second molecular sieve at -196 °C for 30 minutes. Analyte oxygen was expanded directly from the second molecular sieve into one side of the dual inlet of the isotope ratio mass spectrometer by heating to > 110°C for 30 minutes. Simultaneous measurements of <sup>33</sup>O<sub>2</sub>/<sup>32</sup>O<sub>2</sub> and <sup>34</sup>O<sub>2</sub>/<sup>32</sup>O<sub>2</sub> (yielding <sup>17</sup>O/<sup>16</sup>O and <sup>18</sup>O/<sup>16</sup>O, respectively) were made on a ThermoFinnigan Delta-Plus mass spectrometer. Six blocks of 20 cycles, each cycle consisting of an 8 second integration, comprised each measurement.

**Results and Discussion:** HCl treatment caused sample mass decrease as follows: SM43 went from 3.65 mg to 1.17 mg, while SM51 went from 3.45 to 0.82 mg (around 33 and 24 % remained, respectively). Some of the mass loss can be attributed to loss of the super fine fraction during washing but the vast majority can be attributed to carbonate mineral dissolution.

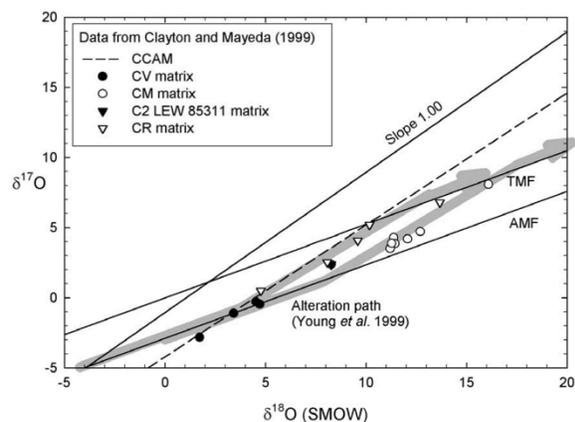


**Figure 1:** Oxygen three-isotope plot of SM fragments measured. Calcite, Dolomite, UCSD-SM43, and SM51 data are published [1]. SM43, SM43-HCl, and SM51-HCl were measured at UCLA for this study. Note, slope 1.00 line, representing unaltered primitive materials; the TMF, representing terrestrial fractionation; and the AMF (Allende fractionation line) with a  $\Delta^{17}\text{O}$  of -3.0, relative to the TMF.

There are two possible explanations for the isotopic compositions of the HCl-treated samples. The simplest is that these data represent the isotopic composition of the residual silicate fraction. This is unlikely when taking into account the published isotopic compositions of the carbonate measured by SIMS (also in Figure 1, [1]). In order for mass balance to hold true the dissolved carbonate fraction would have an isotopic composition outside of the measured envelope for the majority of SM fragments.

Another explanation is that these samples were contaminated by our lab water during HCl treatment. This contamination was likely in the form of isotopic exchange between water and both carbonates (that didn't dissolve) and phyllosilicates. Both of these would cause a positive isotopic shift due to fractionation during exchange, while diluting the  $\Delta^{17}\text{O}$  value and bringing it closer to the TMF. However, the temperature of our HCl treatment was sufficiently high that we would not have expected shifts to such high  $\delta^{18}\text{O}$  value.

Either way, the existence of alteration products and bulk samples on a fractionation line similar to the Allende Mass Fractionation line [4] suggests that alteration was the result of fluid flow along a temperature gradient with the altering fluid coming to various degrees of exchange equilibrium with the surrounding host rocks and visa-versa. These data are consistent with CM and CR data, which also show AMF line origins with alteration products taking slightly steeper trajectories toward TMF compositions (Figure 2). This is the result of effectively changing the water/rock ratio causing the isotope composition of the exchanged material to move from a line dominated by a primitive source (AMF) to a water dominated system lying somewhere above the TFM line.



**Figure 2.** Oxygen three-isotope plot showing published matrix compositions of CC rocks [3] and al-

teration paths proposed by [4] and [5]. The predicted alteration paths from rock-dominated compositions along the AMF line to water-dominated compositions just above the terrestrial mass fractionation line (TMF) are represented by the two grey arrows. The two arrows depict different temperature regimes. CV matrix apparently comes from rock-dominated regions while CM matrix and CR matrix are transitional. CI data would plot near the upper end of the grey arrows and are representative of water-dominated regions.

**References:** [1] Jenniskens P., Fries M. D., Yin Q. Z. (2012) *Science* 338, 1583. [2] T. Sharp (1990). *Geochimica et Cosmochimica Acta* 54, 1353 [3] Clayton R. N. and Mayeda T. K. (1999) *Geochimica et Cosmochimica Acta* 63, 2089-2104. [4] Young E. D., Ash R. D., England P. and Rumble D., III (1999) *Science* 286, 1331-1335. [5] Young E. D. (2001) *Philosophical Transactions of the Royal Society of London A* 359, 2095-2110.