Isotopic Composition of Carbonates in Antarctic Ordinary Chondrites and Miller Range Nakhites: Insights into Martian Amazonian Aqueous Alteration. M. E. Evans\textsuperscript{1,2}, P. B. Niles\textsuperscript{2}, D. R. Locke\textsuperscript{3}, P. Chapman\textsuperscript{1} (michael.e.evans@nasa.gov) \textsuperscript{1}Texas A\&M University, College Station, Tx; \textsuperscript{2}NASA Johnson Space Center, Houston, Tx; \textsuperscript{3}HX5-Jacobs JETS Contract–NASA Johnson Space Center, Houston, Tx.

**Introduction:** The martian surface contains features of ancient fluvial systems. Stable isotope analysis of carbonates that form in aqueous systems can reveal their formation conditions. The Nakhlite meteorites originally formed on Mars 1.3 Ga and were later exposed to aqueous fluids that left behind carbonate minerals \cite{1}, thus analysis of these carbonates can provide data to understand Amazonian climate conditions on Mars. Carbonates found in the Nakhlite meteorites contain a range of $\delta^{13}$C values, which may be either martian carbonates or terrestrial contamination. To better understand terrestrial weathering products and martian carbonate formation processes, we conducted a set of carbonate isotope analyses on Antarctic meteorites focusing on Miller Range (MIL) Nakhites as well as Ordinary Chondrites (OCs) (Figure 1)\cite{1-11} \cite{12}. OCs of petrology type H, L, and LL 3-6 were selected since they are not expected to contain preterrestrial carbonates, yet they have visible evaporite minerals on the fusion crust indicating terrestrial alteration. These cryogenically formed terrestrial carbonates may also provide an analog for cryogenic carbonate formation on Mars.

**Methodology:** Meteorite samples of ~1.2g were gently crushed and sieved to a size of <700 µm, acidified, reacted, and extracted to collect CO\textsubscript{2} cryogenically using standard techniques \cite{7}. The carbonates were reacted with 1.2-1.5 ml of 100% H\textsubscript{3}PO\textsubscript{4} at 30°C and 150°C. The CO\textsubscript{2} was extracted at three different steps: 1) Rx0 after 1 hour at 30°C; 2) Rx1 after 18 hours at 30°C, and 3) Rx2 after 3 hours at 150°C. The CO\textsubscript{2} was separated from other condensable gases using a TRACE GC with a Restek HayeSep Q 80/100 6’ 2mm stainless column. Stable isotope measurements were then made on a Thermo MAT 253 IRMS in Dual Inlet mode. The carbonate concentration was determined based on calcite standard correlations to the GC CO\textsubscript{2} peak count. Study accuracy is $\delta^{13}$C±0.76‰, $\delta^{18}$O±1.58‰ (with 2σ standard deviation).

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**Figure 1:** Comparison of new results for Ordinary Chondrite (OC) meteorites, new results for Miller Range (MIL) Nakhites, and prior martian meteorite results, show carbonate stable isotope values from distinct carbon reservoirs.
Results and Discussion: Ten OC meteorite samples from three Antarctic regions (RBT, ALH, and MIL) were analyzed. These contain terrestrial Ca-rich carbonates with δ13C values clustering around +6‰, which is consistent with equilibrium formation from Earth atmospheric CO₂ at 15°C. Siderite or magnesite fractionation may create slightly heavier carbonate δ13C, as seen in the OC Rx2 results, but fractionation values for these minerals are not well understood at low temperatures.

The range of measured δ18O from OC terrestrial carbonates is +3‰ to +30‰. This is heavier than the expected δ18O < 0‰ if Antarctic meteoric melt water δ18O < -50‰ and equilibrium fractionation at 0°C-15°C [13]. A possible explanation is that the heavier OC carbonates form in a thin-film environment with such small amounts of water that there is a substantial contribution of δ18O from atmospheric CO₂ with δ18O = +41‰ [14].

A δ18O mixing model can be created with Earth atmospheric CO₂ and meteoric water as end members (Figure 2). Mixing various ratios of each known end member produces boundary lines that can be mapped onto measured OC results. This model predicts the OC Ca-rich carbonates form with 60%-90% contribution from atmospheric CO₂ at 0°C, and the Fe/Mg-rich carbonates form with 40%-60% contribution from atmospheric CO₂. The predicted Ca-rich carbonate δ13C in equilibrium with the atmospheric CO₂ at 0°C and 15°C is also shown on Figure 2.

The MIL Nakhlite carbonates vary in δ18O from +7.9‰ to +26.6‰. This is not typical for formation from hydrothermal environments, but may be explained using the OC carbonate mixing model with 1) same Mars mixing ratios as terrestrial carbonates, and 2) Mars meteoric water δ18O ≈ -65‰ (see Figure 3) [1, 3, 8, 9].

Conclusions: OCs contain terrestrial Ca-rich and Fe/Mg-rich carbonates possessing variable δ18O, and δ13C consistent with formation at 15°C in equilibrium with Earth atmospheric CO₂. MIL Nakhlites contain Ca-rich and Fe/Mg-rich carbonates possessing variable δ18O that can be explained with a mixing model of endmembers for Mars meteoric water and Mars atmospheric CO₂. The variability in MIL Nakhlite δ18O values could be the result of low temperature, low water conditions during the Amazonian period on Mars.