OXYGEN ISOTOPIC EVIDENCE FOR AQUEOUS ACTIVITY ON MARS: $\delta^{18}O$ of LAFAYETTE IDDINGSITE.

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This study was prompted by the observation that oxygen in Lafayette is significantly enriched in ^{18}O over than that in Nakhla, $\delta^{18}O$ =5.3‰ vs. 4.7‰ [1] (all relative to SMOW, Figure 1) even though both meteorites have essentially the same $\delta^{18}O$ for their olivines (~4.0‰) and augites (~4.8‰) ([1], Table 1 of [2]). A possible source of this ^{18}O-enriched oxygen in Lafayette is preterrestrial aqueous alteration material, which is much more abundant in Lafayette than in Nakhla [3-5]. This alteration material, "iddingsite," in both meteorites consists principally of smectite clay and ferrihydrite replacing magmatic olivine and siliceous glass [4,6]. To test this hypothesis, separates of augite, olivine, and "iddingsite" were extracted from Lafayette and analyzed for oxygen isotopes by laser fluorination [2].

Oxygen isotope results reported here are consistent with previous analyses using this and other techniques [1,2] for $\delta^{18}O$ and $\delta^{17}O$. Our analyses of Lafayette augite and olivine are within analytical error of those of [a] for $\delta^{18}O$, although there may be a slight systematic enrichment in $\Delta^{17}O$ of 0.16‰. The ~30% "iddingsite" sample is significantly enriched in ^{18}O over unaltered olivine (Table 1 of [2]), and the pure "iddingsite" was the most enriched of all. Unfortunately, our sample of "iddingsite" was too small to give a precise $\delta^{17}O$ value.

^{18}O-ENRICHED CARRIER: The "iddingsite" sample yielded $\delta^{18}O$=14±2‰, confirming that it is an ^{18}O-enriched carrier. In fact, it is probably the only ^{18}O-enriched carrier, as observed abundances of the alteration materials are consistent with abundances suggested by oxygen isotopes. First, the altered olivine is estimated visually to contain 25-50% alteration material; this estimate is consistent with the $\delta^{18}O$ of the "iddingsite"-enriched sample, which can be modeled as ~70% unaltered olivine (4.0‰) and ~30% "iddingsite" (~7.1‰). Second, bulk Lafayette contains 2-4 modal percent "iddingsite" as determined from petrography and measurements of bulk H_2O [3,4]. This estimate is consistent with the $\delta^{18}O$ of Lafayette bulk (5.18‰ [2]), which can be modeled as 95% Nakhla bulk (4.73‰) and 4% "iddingsite" (15‰) Thus, there is no need for any ^{18}O-enriched carrier besides "iddingsite."

IMPLICATIONS: The recognition of significant ranges of oxygen composition among the SNC meteorites and their minerals has important implications for the aqueous geochemistry of Mars. Here, we recognize at least three oxygen components: "iddingsite" plus water, bulk Mars, and "crust."

<u>"Iddingsite" and Water.</u> Assuming oxygen isotopic equilibrium between water and "iddingsite," the oxygen isotope composition of the water that altered Lafayette, can be estimated to be $\delta^{18}O$~-5‰ from our analysis of the "iddingsite." The mineralogy of the "iddingsite" implies formation at low temperature, probably <70°C [4]. Oxygen isotope fractionation for smectite/water at 50°C [7] implies water in equilibrium with the "iddingsite" of $\delta^{18}O$~-5‰. This value is consistent with water that has reacted with basaltic minerals at moderate to low T (<300°C; [8]). It is also consistent with the temperatures inferred for carbonate deposition in ALH84001 [9].

<u>Bulk Mars</u>. The oxygen isotopic composition of Mars is taken as that of EET79001A & B, $\delta^{18}O$ =4.30±0.05‰ and $\delta^{17}O$ =2.53±0.05‰ [1], following the convention in terrestrial petrology that oxygen in the Earth's mantle may be taken as that of basalts derived directly from the mantle: $\delta^{18}O$≅5.8‰, $\delta^{17}O$≅3.0‰. Both lithologies of EET79001 appear to meet this criterion [10]. The trapped atmosphere component in EET79001 [11] contributes negligibly to its oxygen budget.

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This estimated oxygen composition for Mars has interesting planetologic consequences. Mars' $\delta^{18}O$ is 1.5‰ lower than that of the Earth or the Moon, while Mars' $\Delta^{17}O$ is greater by 0.3‰. We have become accustomed to seeing oxygen isotopic data define arrays of either slope-1 or slope-1/2 on a $\delta^{17}O$ vs. $\delta^{18}O$ plot. However, bulk Earth and bulk Mars are not related by either type of line. Alternatively, martian mantle and eucrites (Juvinas [1]) fall reasonably close to a slope-1 line. The meaning of this observation is not clear, but SNC's and eucrites have other chemical similarities, such as similar Fe/Mn ratios.

"Crust". Oxygen in the magmatic minerals of Nakhla, Lafayette, Zagami, and Shergotty is relatively heavy compared to the nominal Martian mantle. The augites of Nakhla and Lafayette could conceivably have been raised to their current value of $\delta^{18}O$~4.8‰ from EET's value of ~4.3‰ by exchange with heavier waters. Analysis of plagioclase/maskelynite from these rocks would evaluate this possibility. The heavy oxygen in Shergotty and Zagami cannot be explained by aqueous alteration, as neither rock is significantly altered. However, the initial ε(Nd) of these basalts suggests that their parent magmas assimilated significant amounts of crustal materials, which could themselves have been altered.

The large difference in $\delta^{18}O$ between "iddingsite" and bulk Lafayette suggests that other weathering and alteration products should be analyzed isotopically to evaluate aqueous processes on Mars.

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