DISPERSION OF OXYGEN ISOTOPIC COMPOSITIONS AMONG 42 MARTIAN METEORITES DETERMINED BY LASER FLUORINATION: EVIDENCE FOR ASSIMILATION OF (ANCIENT) ALTERED CRUST.

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Introduction: Improvements in techniques for oxygen isotopic analysis by laser fluorination (LF) [1] now permit more accurate and precise data to be determined on much smaller specimens than was possible previously. We have undertaken a selective survey of LF data for Martian meteorites, augmented by new analyses, in order to assess whether observed variations might be due to mantle source heterogeneities (as inferred from radiogenic isotopic systems) or else result from assimilation of altered crustal rocks.

Database and New Data: Measurements made at the Geophysical Laboratory, Open University, University of New Mexico, University of Western Ontario and University of Göttingen on many specimens were compiled, mainly from articles, abstracts and Meteoritical Bulletin classifications. In addition, new analyses of 22 acid-washed whole rocks and one pyroxene separate were obtained (all values in per mil):

	$\delta^{17}O$	$\delta^{18}O$	$\Delta^{17}O$
Los Angeles	2.788	4.717	0.307
[ebsherg]	2.729	4.567	0.279
NWA 817	2.553	4.365	0.257
[nakhlite]	2.520	4.184	0.319
NWA 856	2.602	4.522	0.223
[ebsherg]	2.748	4.625	0.327
NWA 1110	2.600	4.325	0.322
[eosherg]	2.499	4.112	0.338
NWA 1195	2.422	4.040	0.299
[doosherg]	2.425	4.011	0.317
NWA 1460 pigeonite	2.475	4.193	0.270
[BMbsherg]	2.391	4.002	0.286
NWA 2046	2.470	4.144	0.290
[doosherg]	2.442	4.024	0.325
NWA 2626	2.584	4.383	0.279
[doosherg]	2.472	4.151	0.288
NWA 2646	2.622	4.521	0.244
[BMgsherg]	2.413	4.050	0.283
NWA 2800	2.587	4.448	0.248
[ebsherg]	2.526	4.272	0.279
NWA 2975/2986	2.725	4.647	0.280
[ebsherg]	2.673	4.586	0.260
	2.712	4.606	0.290
	2.540	4.412	0.219
NWA 3171	2.701	4.499	0.334
[ebsherg]	2.587	4.218	0.368
NWA 4468	2.190	3.600	0.296
[eosherg]	2.219	3.784	0.229
NWA 4480	2.463	4.194	0.257
[BMbsherg]	2.397	4.013	0.286
NWA 4797	2.148	3.564	0.274
[BMwsherg]	2.274	3.841	0.254
NWA 4925	2.593	4.491	0.230
[doosherg]	2.497	4.355	0.206
NWA 5029	2.626	4.435	0.293
[ebsherg]	2.603	4.439	0.268
NWA 5298	2.541	4.316	0.271
[ebsherg]	2.554	4.237	0.325
Dhofar 019	2.569	4.474	0.216
[doosherg]	2.388	4.060	0.252
Dhofar 378	2.371	4.040	0.246
[ebsherg]	2.747	4.635	0.309
	2.754	4.741	0.261
[ebsherg]	2.566	4.374	0.266

Abbreviations: e = enriched; d = depleted; BM = 'Bulk Mars'; b = basaltic; o = olivine-phyric; oo = ol-opx-phyric; sherg = shergottite; g = melagabbroic; w = wehrlitic

Replicate analyses of whole subsamples (e.g., NWA 856) vary in $\Delta^{17}O$ by up to ± 0.04 per mil (1σ) from the mean; for 4 subsamples of NWA 2975/2986 the range is 0.07 per mil. New analyses for a bulk sample of NWA 3171 support previous results on separated pyroxene and maskelynite [2], showing that this shergottite has an unusually high *mean* $\Delta^{17}O$ value. Yet the large range for mineral separates ($\Delta^{17}O$ = 0.278-0.427 per mil) also indicates that oxygen isotopes are not equilibrated within this single specimen. In contrast, replicates for other specimens are more consistent.

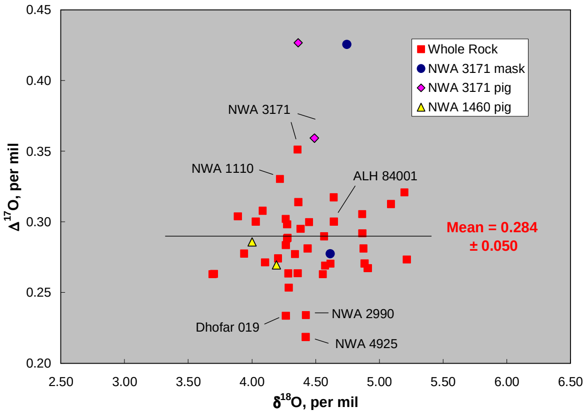

Figure 1 (above) shows that the mean $\Delta^{17}O$ value for averaged LF replicate analyses of 42 Martian meteorites is 0.284 per mil, with a range from 0.22 to 0.36 per

mil. There are no discernible correlations between $\Delta^{17}O$ and lithology or formation age. This range of 0.14 per mil is beyond the analytical uncertainties, and is considerably greater than the observed ranges in LF data for unaltered terrestrial crustal and mantle rocks, for Apollo samples+lunar meteorites and for 9 angrites. However, it is similar to ranges in LF data for HEDOD meteorites (+ mesosiderites) and for brachinites (including GRA 06128) [e.g., 3, 4]. Since all of the samples considered here were acid-washed, we can exclude scatter from variable terrestrial weathering effects (which should apply to analyzed angrites as well).

Mineral Compositional Zoning: It has been recognized for some time that pyroxene grains in shergottites have very irregular compositional zoning in major elements (see Figure 2), and plagioclase (maskelynite) is not homogeneous either. Although no *in situ* study of variations in oxygen isotopes within minerals has yet been conducted, significant variations in Li isotopes were found in pyroxenes of shergottite NWA 480 [5].

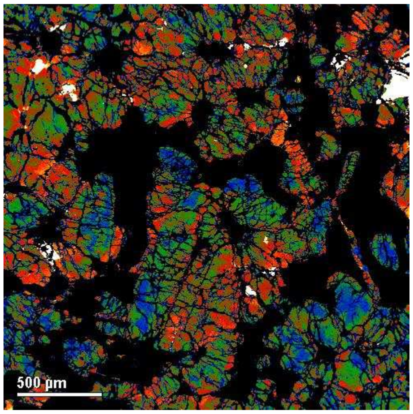

Figure 2. *BSE image of shergottite NWA 3171 showing "chaotically" zoned pyroxene (colors), maskelynite (black) and Fe-Ti oxides (white).*

Discussion: Robotic MER analyses have shown that many outcropping igneous rocks in Gusev Crater have been extensively altered by sulfate- and halogen-bearing hydrothermal fluids, probably >3 Ga ago [6]. Furthermore, it has been shown that carbonate in ALH 84001 and secondary alteration phases in nakhlites have higher $\Delta^{17}O$ values than the primary igneous assemblages (from 0.8 to 1.3 per mil) [7], and it might be inferred that altered rocks like those at the MER sites have similarly (or more?) elevated values.

It is possible in principle that ascending, younger Martian magmas could have interacted with such altered materials in near-surface reservoirs [8], and if such an assimilant had an extreme isotopic composition it would not take very much of it to produce detectable (and potentially highly variable) effects in crystallizing magma bodies. The mineralogy of altered Gusev rocks is modeled to be dominated by Ca-Mg-Fe sulfates, Fe oxides/hydroxides, Ca phosphates, halides and silica [6, 9]. Progressive assimilation or thermal decomposition of such materials by shergottite magma could produce localized melt domains of highly variable composition, which may not be readily homogenized by mixing over the timescales of crystallization, and could be manifested in very variable zonal domains in growing mineral crystals (especially for Ca in pyroxenes). Extreme oxygen isotopic compositions of such assimilants could impart large $\Delta^{17}O$ variations in growing minerals.

The alternative hypothesis of inherited mantle heterogeneities in oxygen isotopes would be in concert with other evidence of ancient isotopic heterogeneity, especially the ^{182}W and ^{142}Nd anomalies in nakhlites, Chassigny and various shergottites [10]. However, it is unlikely that primary accretionary heterogeneities in oxygen isotopes could survive so long within a differentiated body such as Mars, which evidently had at least a short-lived magma ocean [11] followed by mantle plume activity until at least 200 Ma ago.

If the "enriched" nature of some shergottites is a product of variable assimilation of components derived from ancient, highly altered crustal rocks, then inferences about exact crystallization ages and source characteristics may be called into question, but likewise claims of very ancient shergottite formation ages based on Pb-Pb isotope arrays [12] may be untenable.

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