

**OXYGEN ISOTOPE COMPOSITIONS OF MINERAL SEPARATES FROM SNC METEORITES: CONSTRAINTS ON SNC PARENTAL MAGMAS.** M. B. Channon, E. M. Stolper, and J. M. Eiler, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125 (mchannon@gps.caltech.edu)

**Introduction:** Martian (SNC) meteorites are igneous rocks from young (except for ALH 84001, which is much older), thick lava flows or shallow intrusions [1]. The shergottites ('S' of SNC) can be categorized according to LREE depletion into highly, moderately, and slightly depleted groups [1]. The La/Lu ratio (and other depletion indicators) is positively correlated with oxygen fugacity, and this has been interpreted as evidence of mixing of two source components [1-4]. The inferred end members could be distinct mantle components (e.g., enriched, oxidized domains entrained in the ambient depleted, reduced mantle), perhaps residual to early planetary differentiation [3,5]; alternatively, depleted, reduced magmas could be partial melts of a reduced peridotitic mantle, whereas enriched, oxidized magmas might contain large fractions of oxidized, aqueously altered crustal rocks [2, 6].

Whole-rock SNC oxygen isotope ratios appear to correlate with oxygen fugacity and degree of depletion [3]. This relationship has been interpreted as evidence that martian magmas formed by melting of a depleted, reduced mantle followed by variable amounts of contamination by oxidized,  $^{18}\text{O}$ -rich, aqueously altered crust rather than by mixing of melts from two mantle domains.

On Earth, oxygen isotope ratios of mantle peridotites differ systematically from crustal materials (mainly due to aqueous alteration in the shallow crust) [7, and references therein]. This contrast in oxygen isotope composition has been used to constrain crustal assimilation processes and source heterogeneity in terrestrial magmas [8-9]. If the martian crust is similarly enriched in  $^{18}\text{O}$  due to aqueous alteration, this approach could also be applied to quantifying crustal assimilation on Mars. This might be the case if phyllosilicates such as those detected on Noachian crust by OMEGA [10-11] are volumetrically significant components of the crust. Subtle variations in  $\Delta^{17}\text{O}$  in the SNC's (even within a single meteorite) have also been interpreted as evidence of SNC magma source heterogeneity, possibly from crustal assimilation [12].

Previously available oxygen isotope data may not adequately constrain the  $\delta^{18}\text{O}$  values of martian magmas [13]: (1) Many SNC's contain high- $\delta^{18}\text{O}$  alteration phases from martian and/or terrestrial weathering; and, (2) many SNC's are cumulates that likely differ in  $\delta^{18}\text{O}$  from the magmas from which they accumulated. Furthermore, the variation recently found in  $\Delta^{17}\text{O}$  by [12]

**Table 1.** Data obtained by  $\text{CO}_2$  and  $\text{O}_2$  analyses. All errors reported on an average (numbers in parentheses are the number of analyses that were averaged) are standard errors. All errors reported on single measurements are  $1\sigma$  of the UWG-2 standard ran on the same day as the sample. Px, pyroxene; Msk, maskelynite; Ol, olivine; Cpx, clinopyroxene; Opx, orthopyroxene.

Sample	Phase	$\delta^{18}\text{O}$ (n)	$\Delta^{17}\text{O}$ (n)
<b>Basaltic Shergottites</b>			
Shergotty	Px	4.66±0.04 (3)	0.301±0.013 (1)
	Msk	5.12±0.16 (2)	
NWA 2986*	Px	4.52±0.01 (2)	
	Msk	5.02±0.10 (2)	
<b>Lherzolithic Shergottites</b>			
ALHA77005	Px	4.72±0.07 (1)	
	Ol	4.28±0.05 (6)	0.318±0.008 (1)
NWA 1950	Px	4.62±0.05 (4)	
	Ol	4.33±0.03 (6)	0.304±0.009 (2)
<b>Olivine-phyric Shergottites</b>			
DaG 476	Px	4.75±0.02 (2)	
Dho 019	Px	4.91±0.07 (1)	
NWA 2046	Px	4.62±0.09 (2)	
	Ol	4.27±0.17 (2)	
<b>Nakhlites</b>			
Lafayette	Cpx	4.83±0.06 (4)	
	Ol	4.68±0.09 (4)	
Nakhla	Cpx	4.75±0.07 (4)	0.315±0.023 (1)
NWA 998	Cpx	4.87±0.04 (8)	0.309±0.007 (4)
	Cpx <sup>†</sup>	4.88±0.03 (5)	0.320±0.002 (1)
	Cpx <sup>‡</sup>	4.78±0.04 (5)	0.332±0.014 (1)
	Avg Cpx	4.85±0.02 (18)	0.314±0.006 (6)
	Ol	4.60±0.10 (4)	
<b>Orthopyroxenite</b>			
ALH 84001	Opx	4.97±0.06 (4)	0.302±0.013 (1)
<b>Average <math>\Delta^{17}\text{O}</math></b>			0.311±0.004

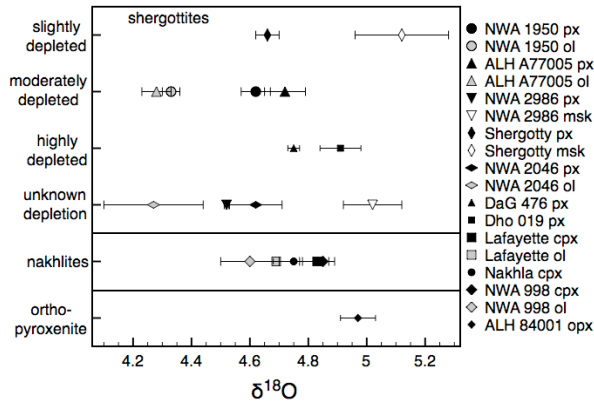
\*NWA 2986 is not yet an official name.

<sup>†</sup>Material washed with HCl; <sup>‡</sup>Material washed with HF.

was not found by [14], and is worth exploration. This study aims to define better the  $\delta^{18}\text{O}$  and  $\Delta^{17}\text{O}$  of magmas parental to the SNC's by examining mineral separates rather than whole-rock samples; by subjecting samples to various pre-treatment procedures; and by replicating sample analyses to reduce external errors.

**Methods:**  $\delta^{18}\text{O}$  values of olivine (ol), clinopyroxene (cpx), orthopyroxene (opx), or a mixture of opx and cpx (px), and maskelynite (msk) were measured at Caltech using  $\text{CO}_2$  laser fluorination. Methods of  $\delta^{18}\text{O}$  measurements are described in [15-16]. Methods of  $\Delta^{17}\text{O}$  measurement are similar to those in [14] except that a MAT252 mass spectrometer was used. Mineral

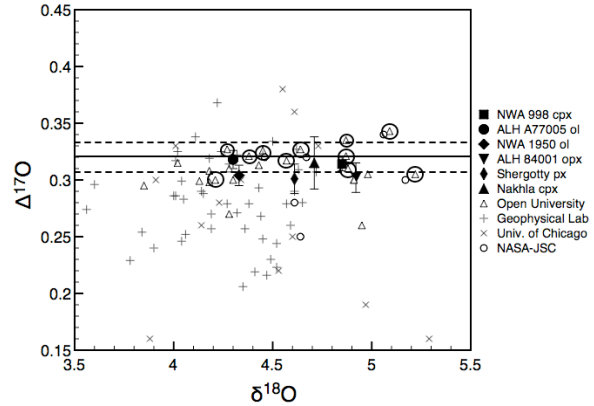
separations were done by hand picking under a binocular microscope; phases were verified using Raman spectroscopy and SEM. Aliquots of cpx separates from sample NWA 998 (a highly weathered sample) were washed in 2.5M HCl for 20 min at 90°C, and a subset of these aliquots were washed in 5% HF for 10 min at room temperature, then rinsed with 2.5M HCl and again with deionized H<sub>2</sub>O (all were then dried prior to analysis).



**Figure 1.** Measurements of  $\delta^{18}\text{O}$  from this study. The shergottites are grouped according to depletion. The black symbols are pyroxene, grey symbols are ol, and open symbols are msk. All error bars are  $\pm 1$  standard error of the mean, except on single measurements (see Table 1) they are  $1\sigma$  of the UWG-2 standard ran on the same day as the meteorite.

**Results:** Seventy-one measurements of  $\delta^{18}\text{O}$  were made on ol, and/or px (from here on this term refers to opx, cpx, or a mixture of both; see Table 1), and/or msk from 11 SNC samples (Table 1; Fig. 1). The  $\delta^{18}\text{O}$  measurements yield similar results whether measured using CO<sub>2</sub> or O<sub>2</sub>. The differences in  $\delta^{18}\text{O}$  between co-existing ol and px separates and between px and msk separates are comparable to those expected for equilibrium magmatic fractionations ( $\sim 0.35$  ‰ and  $\sim 0.40$  ‰ respectively). Twelve measurements of  $\Delta^{17}\text{O}$  were measured on ol or px from 6 samples (Table 1; Fig. 2).

**Discussion:** The results from this study suggest that liquids from which the shergottites crystallized vary in  $\delta^{18}\text{O}$  by significantly less ( $\sim 0.4$  ‰) than previously inferred from whole rock measurements ( $\sim 1.0$  ‰). Furthermore, our data set for  $\Delta^{17}\text{O}$  differs from the martian fractionation line as reported by [14] ( $0.321 \pm 0.013$  ‰) by  $\sim 0.020$  ‰, and our  $\Delta^{17}\text{O}$  data are much less variable than previously reported (i.e., they span a range of  $\sim 0.03$  ‰; see Fig. 2). Our data so far suggest a martian  $\Delta^{17}\text{O}$  value of  $0.311 \pm 0.004$  ‰. The lack of variation in  $\Delta^{17}\text{O}$  contrasts greatly with those reported in [12, 17, 18], but only slightly with variations reported in [14].



**Figure 2.** Measurements from this study are in black. Measurements from 4 other labs are added for comparison. Circled measurements are from [14]. The martian fractionation line, as reported by [14], is shown for reference. All previous data come from [12, 14, 17-22] or from The Meteoritical Society bulletins.

Pyroxenes from highly depleted shergottites are slightly higher ( $\sim 0.2$  ‰) in  $\delta^{18}\text{O}$  than those from other shergottites (Fig. 1); this subtle difference implies a negative correlation with La/Lu and oxidation, much smaller and opposite in sign than previous reports [3] (and opposite that expected for assimilation of altered crust for the less depleted samples). The validity of the slightly higher  $\delta^{18}\text{O}$  values of pyroxene from highly depleted shergottites will be better known once Dho 019 px has been replicated and its ol measured. The nakhlites and orthopyroxenite also have higher  $\delta^{18}\text{O}$  values, and both are relatively oxidized [23-24]. This would be consistent with assimilation of altered crust by their parent magmas (though additional work is needed to explore this possibility). Subtle variations in  $\delta^{18}\text{O}$  found in this study imply that no shergottite parent magmas assimilated more than  $\sim 5$  % aqueously altered phases.

**References:** [1] Bridges J. C. and Warren P. H. (2006) *J. Geol. Soc.*, 163, 229-251 [2] Wadhwa M. (2001) *Sci.*, 291, 1527-1530 [3] Herd C. D. K. (2003) *M&PS*, 38, 1793-1805 [4] Jones J. H. (2003) *M&PS*, 38, 1807-1814 [5] Borg L. E. et al. (2003) *GCA*, 67, 3519-3536 [6] Herd C. D. K. et al. (2002) *GCA*, 66, 2025-2036 [7] Eiler J. M. (2001) *MSA, Reviews in Mineralogy*, 43, p.319-364 [8] Davidson J. P. et al. (2005) *J. Volcanology & Geotherm. Res.*, 140, 157-170 [9] Garcia M. O. et al. (2008) *J. of Petrology*, 49, 757-769 [10] Bibring J.P. et al. (2006) *Sci.*, 312, 400-404. [11] Mangold N. et al. (2007) *J. of Geophys. Res.*, 112, E08S04 [12] Rumble D. and Irving A. J. (2009) *LPSC XL*, #2293 [13] Channon M. C. et al. (2009) *LPSC XL*, #2450 [14] Franchi I. A. et al. (1999) *M&PS*, 34, 647-661 [15] Valley J. W. et al. (1995) *GCA*, 59, 5223-5231 [16] Eiler J. M. et al. (2000) *J. of Petrology*, 41, 229-256 [17] Clayton R. N. and Mayeda T. K. (1996) *GCA*, 60, 1999-2017 [18] Romanek C. S. et al. (1998) *M&PS*, 33, 775-784. [19] Irving A. J. et al. (2002) 65<sup>th</sup> Ann. Met. Soc. Mtg. #5225 [20] Gnos E. et al. (2002) *M&PS*, 37, 835-854 [21] Gillet P. et al. (2005) *M&PS*, 40, 1175-1184 [22] Beck P. et al. (2006) *GCA*, 70, 2127-2139 [23] Ghiorso M. and Sack R. O. (1991) *Contrib. Mineral. Petrol.*, 108, 485-510. [24] Herd C. D. K. and Papike J. J. (1999) *LPSC XXX*, #1503