OXYGEN ISOTOPE COMPOSITIONS OF MINERAL SEPARATES FROM MARTIAN METEORITES: CONSTRAINTS ON SNC PARENTAL MAGMAS

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ABSTRACT

Many discoveries have been made suggesting that water once flowed on the surface of Mars. Igneous rocks from Mars (in the form of meteorites) can be studied to determine whether or not their magma sources have assimilated crust that has been altered by water such as an ocean or river. On Earth, unaltered igneous rocks that come from the mantle have a uniform oxygen isotopic composition. Igneous rocks coming from magma that intruded and assimilated aqueously altered crust have a different composition. In this study, oxygen isotopes were measured in mineral separates from 15 different martian meteorites by laser fluorination. Olivine from meteorites classified as shergottites and chassignites measured in this study were found to have the same isotopic composition, whereas olivine from nakhlites have a different composition. Shergottites and chassignites may have never been in contact with water and therefore reflect the oxygen isotopic composition of igneous minerals from the mantle. Nakhlites, on the other hand, may come from a region of Mars that was affected by water.

INTRODUCTION

Mars is a terrestrial planet similar to Earth. There are signs that liquid water existed on the surface in the past. Liquid water is the foundation for life, as we know it. If there was enough water that persisted for long enough, it is possible that Mars harbored and may still harbor simple forms of life. We have samples from Mars in the form of meteorites. The martian meteorites (also known as SNC meteorites according to the type specimens shergotty, nakhla, and chassigny) are all igneous rocks that either come from volcanic lava flows, or magma that intruded into the shallow crust but did not quite break the surface. They are classified according to petrologic type into 6 groups: basaltic shergottites, lherzolitic shergottites, olivine-phyric shergottites, nakhlites (clinopyroxenites), chassignites (dunites), and ALH 84001 (the only orthopyroxenite). Geochemical evidence (radiogenic isotopes, rare Earth element patterns, and oxygen fugacity) exists that supports the notion that the shergottite magma sources have assimilated aqueously altered crust to varying degrees. However, this evidence is not conclusive, and could also be explained by a heterogeneous mantle. Measuring the oxygen isotopes of these meteorites will reveal whether or not their source magma intruded crust that was penetrated by water at low temperatures, and if so, how much.

On Earth rocks that have been altered by water at low temperature have $^{18}O/^{16}O$ values that are higher than those that have not. In addition, rocks that have not been altered by water at low temperature all have close to the same $^{18}O/^{16}O$

value. Oxygen isotope measurements are typically reported as $\delta^{18}O$ in units of per mil (‰):

$$\delta^{18}O = \left(\frac{{}^{18}O/{}^{16}O_{Sample}}{{}^{18}O/{}^{16}O_{Standard}} - 1 \right) \times 1000$$

Minerals within a rock have different $\delta^{18}O$ values from each other. The proportion of the minerals in the rock dictates the $\delta^{18}O$ value of the whole rock. Martian meteorites do not all have the same mineral proportions. For this reason, it is better to compare the values of specific minerals among meteorites rather than values of whole meteorites.

METHODS

The minerals olivine, pyroxene, and maskelynite (shocked plagioclase) were separated from 15 meteorites. Measurements were made using a technique known as laser fluorination. One and a half mg of sample is placed under vacuum and heated by a CO_2 laser in the presence of BrF_5 gas. The laser causes the bonds of the atoms in the sample to break and the BrF_5 quickly reacts with the cations, and releases the oxygen to form O_2 gas. The O_2 gas is purified using cryogenic traps and converted to CO_2 by reaction with a heated graphite rod. The CO_2 gas is analyzed using a gas source mass spectrometer.

RESULTS

A total of 83 measurements were obtained over the course of this study. There are 25 olivine analyses from 7 of the meteorites, 52 pyroxene measurements from 13 meteorites, and 6 maskelynite measurements from 4 meteorites (Table 1). All shergottite olivine measurements have a $\delta^{18}O_{VSMOW}$ average of 4.28±0.05 ‰. The chassignite NWA 2737 also falls within this range at 4.32 ‰. The nakhlite olivine measurements average to 4.65±0.06 ‰. The shergottite pyroxene measurements average to 4.69±0.10 ‰, the nakhlite pyroxenes to 4.80±0.05 ‰, and ALH 84001 pyroxene is 4.97 ‰. Shergottite maskelynite averages to 5.04±0.12 ‰.

DISCUSSION/CONCLUSIONS

The uniform values of the olivine measurements show that the shergottites and chassignite may represent the $\delta^{18}O$ value for olivine from the mantle. Additionally, this does not support previous geochemical indications of hydrous crustal assimilation, and instead suggests that the previous data may be a result of mantle heterogeneity. The nakhlites, on the other hand, may have assimilated crust that has been hydrously altered into their magma sources because they have higher olivine isotopic composition than the shergottites. Both pyroxene and maskelynite in all meteorite types show more variation in $\delta^{18}O$. This is possibly due to an isotopic fractionation dependence on Ca content, which can vary in both pyroxene and maskelynite. Further characterization of the mineralogy will test this hypothesis.

The seemingly negative result of a uniform isotopic composition for the shergottites and chassignite is an important constraint when estimating water quantity and activity of the martian past. This finding refutes the hypothesis of a past global ocean, and limits any ocean to locations that do not include shergottite and chassignite source regions.

Table 1. All errors reported are standard errors.

Sample	Mineral	Analyses	$\delta^{18}O_{VSMOW}$ (‰)
Basaltic Shergottites			
NWA 2986	Pyroxene	3	4.58±0.05
	Maskelynite	2	5.08±0.03
Shergotty	Pyroxene	3	4.70±0.05
	Maskelynite	2	5.19±0.09
NWA 4468	Pyroxene	2	4.66±0.10
	Maskelynite	1	4.90
Zagami	Pyroxene	2	4.58±0.02
	Maskelynite	1	4.99
Lherzolitic Shergottites			
NWA 1950	Pyroxene	4	4.63±0.05
	Olivine	6	4.35±0.03
ALH A77005	Pyroxene	1	4.72
	Olivine	6	4.28±0.05
Olivine-Phyric Shergottites			
NWA 2046	Pyroxene	2	4.62±0.08
	Olivine	2	4.27±0.17
DaG 476	Pyroxene	2	4.75±0.02
Dho 019	Pyroxene	1	4.91
SaU 005	Pyroxene	1	4.81
	Olivine	1	4.24
Nakhlites			
Lafayette	Pyroxene	5	4.82±0.05
	Olivine	4	4.69±0.09
Nakhla	Pyroxene	4	4.75±0.07
NWA 998	Pyroxene	18	4.84±0.02
	Olivine	4	4.60±0.10
Chassignite			
NWA 2737	Olivine	2	4.32±0.01
Orthopyroxenite			
ALH 84001	Pyroxene	4	4.97±0.06

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