

THE ISOTOPIC COMPOSITION OF MAGNESIUM IN THE INNER SOLAR SYSTEM. R. Chakrabarti¹ and S. B. Jacobsen², ^{1,2}Department of Earth and Planetary Sciences and Origins of Life Initiative, Harvard University, 20 Oxford Street, Cambridge, MA 02138 (¹chakrab@fas.harvard.edu and ²jacobsen@neodymium.harvard.edu)

Introduction: Mg is the third most abundant element in the Earth with a 4-8% mass difference between its three isotopes (masses 24, 25 and 26) which can potentially result in significant Mg isotopic fractionation during low temperature processes. With improvements in Multi-Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS), Mg isotope ratios can now be measured with high precision with analytical uncertainties an order of magnitude better than the early TIMS measurements [e.g. 1]. Mg isotopic fractionation in Earth surface systems are well documented [2-10]. There is a relatively large range in the Mg isotopic composition of terrestrial rocks formed at low temperatures; the lightest values are observed in carbonates ($\delta^{26}\text{Mg} \sim -4.0 \text{ ‰}$) while the heaviest isotopic ratios are found in shales and soils ($\delta^{26}\text{Mg} \sim 0.0 \text{ ‰}$).

Critical to our understanding of the long term evolution of the Mg cycle in surface reservoirs e.g. the Mg isotopic evolution of seawater with time which is recorded in carbonate rocks, is the Mg isotopic composition of the bulk silicate Earth (BSE). However, there is no consensus on the Mg isotopic composition of the BSE. Also, it is important to know: 1) how the Mg isotopic composition of the BSE compares with other differentiated and undifferentiated objects in the Solar System, 2) the range of stable Mg isotopic compositions in other Solar System objects, and 3) is the Mg isotopic composition of the BSE similar to those of chondrites?

There have been some attempts to address the above questions, especially determining the Mg isotopic composition of the BSE [10-15]. The results from the different groups, however, are not consistent with one another although the reason for this discrepancy remains unclear. There is also some controversy as to what samples represent the Mg isotopic composition of the Earth's mantle. While dunites and peridotites typically represent the pristine mantle that can be sampled, these olivine-rich rocks are more easily altered under surface conditions and low-temperature alteration of these mantle-rocks can perturb their Mg isotopic compositions. Fresh basalt samples do not suffer from the possibility of low-temperature surface alteration. However, basalts are products of partial melting of the mantle and Mg isotopic compositions of basalts might not perfectly represent that of the unmelted mantle although, high temperature fractionation of Mg isotopes is expected to be minimal. In addition, although olivines are the major hosts of Mg in the

mantle, orthopyroxenes and to a lesser extent clinopyroxenes also contain significant quantities of Mg and crystallization of olivine and pyroxene from the same melt might fractionate Mg isotopes, but such high-temperature fractionations are expected to be small [12].

Samples: To address the above questions, we have analyzed Mg isotopes in a suite of terrestrial mantle-derived rocks including USGS standards. These include one dunite (DTS-1), one whole-rock harzburgite (PCC-1), co-existing olivines and pyroxenes from two mantle peridotites (San Carlos and Kilbourne Hole) as well as five basalts from a wide range of geographic locations and tectonic settings (MAR and EPR MORBs, Hawaiian and continental basalts) including USGS standards BHVO-1 and BCR-1. In addition, we have also analyzed four whole-rock ordinary (Grady2 and Peace River) and carbonaceous (Allende and Murchison) chondrites, olivines from seven main group (Brenham, Glorietta Mt., Ahumada, Pavlodar, Marjalahti, Finmarken) and Eagle Station group pallasites, three martian meteorites (Nakhla, Zagami and Chassigny) and five lunar samples including three ilmenite basalts (75075, 12045, 12063), one olivine basalt (71569) and one crystalline breccia (14304).

We have also performed a series of experiments to assess the accuracy of our Mg isotope measurements in silicate rocks to firmly establish the range of Mg isotope variations between Solar System objects. As a test of accuracy of our measurements involving chemical purification and mass spectrometry, we have analyzed inter-laboratory pure Mg standards, seawater samples and have prepared three new pure Mg standards.

Analytical Methods: Separation and purification of Mg was performed using Biorad 50W-X12 (200-400 mesh) cation exchange resin in Savillex teflon columns following established protocols [12]. Mg isotope ratios were measured using a GVI Isoprobe-P MC-ICPMS at Harvard University in the static mode by standard-sample bracketing to correct for instrumental mass bias. Each sample or standard was bracketed by measurements of the DSM3 pure Mg metal standard [16]. Purified Mg solutions were introduced using an APEX-Q spray chamber fitted with an additional desolvator (ACM from ESI) and a PFA nebulizer with an uptake rate of 100 $\mu\text{l}/\text{min}$. We used a combination of He and H₂ in the collision cell, a unique feature of the Isoprobe-P, to get rid of isobaric gaseous interferences (e.g. C₂⁺, CN⁺) on all isotopes of

Mg. All our measurements were performed with a resolving power (R_{power} , 5%, 95%) of ~ 1100 . In a given analytical session, a particular sample or standard was measured 3-4 times w.r.t. 4-5 measurements of DSM3. All standards and samples were measured at least in 2 different sessions over 20 months and we report the averages of all these measurements.

Results and Discussion: We have measured the pure Mg standard Cambridge1 [16] 190 times along with chemically processed seawater samples and our results are consistent with certified values. Based on our analyses of terrestrial basalts, dunites and peridotites, we estimate the $\delta^{26}\text{Mg}$ value of the bulk silicate Earth (BSE) at $-0.54 \pm 0.04\text{‰}$ (2SE) w.r.t. DSM3 (Fig. 1). Consistent with a recent report [15] we find that the Mg isotopic composition of clinopyroxenes are heavier than co-existing olivines and orthopyroxenes although the magnitude of this difference varies from 0.2‰ ($\Delta^{26}\text{Mg}_{\text{OL-CPX}}$) in San Carlos to 0.08‰ in Kilbourne Hole. $\delta^{26}\text{Mg}$ of terrestrial basalts are within error of olivines from mantle peridotites. Small mineral fractionations along with differences between components in primitive meteorites (CAIs, chondrules, matrix) [e.g. 10] preclude the resolution of mass dependent fractionation differences smaller than about 0.05‰ between Solar System objects.

Our study shows that the stable Mg isotopic composition of the *bulk silicate Earth is chondritic* ($\delta^{26}\text{Mg} = -0.52 \pm 0.04\text{‰}$). Mg isotopic composition of Mars ($\delta^{26}\text{Mg} = -0.57 \pm 0.02\text{‰}$), Moon ($\delta^{26}\text{Mg} = -0.51 \pm 0.03\text{‰}$) and pallasites ($\delta^{26}\text{Mg} = -0.54 \pm 0.04\text{‰}$) are also similar to chondrites suggesting that stable Mg isotopic composition of inner Solar System is homogeneous with $\delta^{25}\text{Mg} = -0.273 \pm 0.028\text{‰}$ and $\delta^{26}\text{Mg} = -0.535 \pm 0.045\text{‰}$ (Fig. 1). $\delta^{25}\text{Mg}$ and $\delta^{26}\text{Mg}$ of the inner Solar System (ISS) are important reference points for modeling processes of Mg isotopic fractionation and have implications both for planetary surface processes as well as evaporation/condensation processes in the solar nebula.

Although, our above conclusions are in overall agreement with several other workers [e.g. 12], there is still a discrepancy in the absolute Mg isotopic composition of silicate rocks between different groups. Most groups have reported relatively heavier $\delta^{26}\text{Mg}$ in silicate rocks compared to our data. We have performed a series of experiments including standard addition tests to assess the role of analytical artifacts, including matrix effects and mass spectrometry, on the accuracy of Mg isotope ratio determination. There is clear evidence, which is consistent with the work of other workers [e.g. 17], that heavy $\delta^{26}\text{Mg}$ can be produced by analytical artifacts. However, more inter-laboratory work needs to be done to clearly understand the cause

of these discrepancies. The role of analytical artifacts in comparing the $\delta^{26}\text{Mg}$ of BSE and chondrites can be minimized if both sets of measurements are done in the same laboratory. To address the issue of inter-laboratory discrepancies on the Mg isotopic composition of silicate rocks, we have prepared 3 pure Mg standards with wide ranging $\delta^{26}\text{Mg}$ (-3.75 to -0.69‰ with respect to DSM3) as well as a large volume of homogenized olivine from the San Carlos peridotite ($\delta^{26}\text{Mg} = -0.55 \pm 0.06\text{‰}$) for future comparative studies. The wide range in the Mg isotopic composition of these standards makes them valuable inter-laboratory standards for future use. We demonstrate that our results do *not* support the recent claims that: (i) the Earth-Moon system has a unique Mg isotope composition different from chondrites, (ii) the higher $\delta^{26}\text{Mg}$ values (-0.3 to 0.0‰) reported for chondrites, achondrites, terrestrial basalts and peridotites.

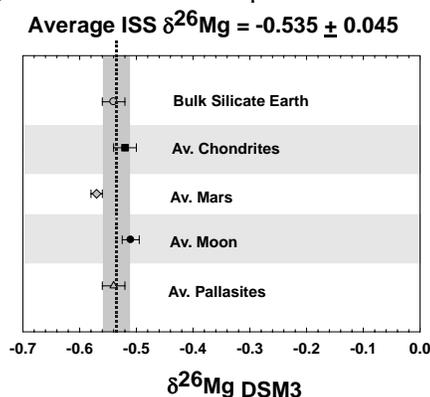


Fig. 1. Stable Mg isotope data for average terrestrial mantle-rocks and minerals, chondrites, pallasite olivines, martian meteorites and lunar basalts and breccia. Error bars represent the external reproducibility in 2SE.

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