MAGNESIUM ISOTOPIC COMPOSITION OF ACHONDRITES AND BEHAVIOR OF MG ISOTOPES DURING MAGMATIC DIFFERENTIATION OF ACHONDRITE PARENT BODIES

F. Sedaghatpour[1, 2] and F.-Z. Teng[1, 3]. [1]Isotope laboratory, Department of Geosciences and Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, USA, [2]Department of Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge, MA 02138, USA; fsedaghatpour@fas.harvard.edu, [3]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA; fteng@u.washington.edu.

Introduction: Meteorites with similar oxygen isotopes are generally assumed to be formed in a relatively limited region of the solar nebula. However, there are some achondrites with similar average oxygen isotopic compositions, but large different chemical compositions (e.g. angrites and brachinites), reflecting different igneous processes of achondrite parent bodies [1]. Hence, chemical and isotopic studies of achondrites can help to understand the general planetary differentiation and chemical evolution of the solar system.

Recent studies of some stable isotopes (e.g., Zn, Si, and Fe) of achondrites and pallasites have shown isotopic fractionation either by volatilization or metal/silicate segregation during their parent bodies' accretion and differentiation [2-4]. However, study of Li isotopes with volatility temperature higher than Zn and lower than Fe and Si reveals no significant Li isotope fractionation during accretion processes and magmatic differentiation of the HEDs' parent body [5]. The knowledge of Mg isotopic composition of achondrites and behavior of Mg isotopes during magmatic differentiation of the parent bodies of these meteorites is limited and controversial [6-8]. Wiechert and Halliday [7] reported heavier non-chondritic Mg isotopic composition for HEDs which is similar to those of the Earth and Mars, suggesting physical separation and sorting of the chondrules and CAIs in proto-planetary disk. By contrast, Mg isotopic analyses of achondrites by others suggested similar chondritic Mg isotopic compositions for the Earth, Mars, Moon, and pallasite parent body [6, 8].

Samples: In order to estimate Mg isotopic composition of achondrites, understand magmatic differentiation of their parent bodies and evaluate the degree of isotopic heterogeneity in the solar system, we have analyzed 22 meteorite samples from different groups of achondrites and pallasites. These samples include 20 meteorites from acapulcoite-lodranite, winonaite-IAB-iron silicate, angrite, aubrite, howardite-eucrite-diogenite (HED), mesosiderite silicates, and ureilite groups and two main-group pallasites, covering a wide range of chemical compositions and oxidation states of their parent bodies.

Analytical methods: Magnesium isotope ratios were measured using a Nu Plasma MC-ICPMS at the University of Arkansas, by standard bracketing method with the internal precision of <±0.09‰ (2SD) for 4 repeat runs of the same sample solution during a single analytical session. Magnesium was separated by cation exchange chromatography, using Bio-Rad 200-400 mesh AG50W-X8 resin in 1 N HNO_3 media following previously established procedures [9-11]. Full procedural replicate analyses of seawater, Allende and Murchison meteorites as reference materials were performed and yielded Mg isotopic compositions similar to the previously published values (11, 12).

Results: All achondrites samples analyzed here along with the bulk Earth and chondrites, seawater, and the Moon from the same laboratory fall on a single mass-dependent fractionation line with a best-fit slope of 0.509 [11-13], consistent with previous studies [11, 14].

δ^{26}Mg values range from -0.27‰ to -0.22‰ in winonaite-IAB-iron silicate group, from -0.37‰ to -0.30‰ in aubrites, from -0.27‰ to -0.16‰ in HEDs, from -0.30‰ to -0.21‰ in ureilites, from -0.31‰ to -0.29‰ in mesosiderites, and from -0.30‰ to -0.29‰ in pallasites. δ^{26}Mg values of two acapulcoite-lodranite and angrite meteorites are -0.23‰ and -0.19‰, respectively. Allende, Murchison, and seawater samples yielded weighted average δ^{26}Mg values of -0.30 ± 0.03‰ (2SD, n = 5), -0.35 ± 0.03‰ (2SD, n = 3), and -0.86 ± 0.04‰ (2SD, n = 4), respectively, which are in agreement with previous data [10, 12]. The calculated non-mass-dependent anomalies (δ^{26}Mg*) in achondrites analyzed here are small (~0.000-0.068‰) and not resolvable at current analytical precision.

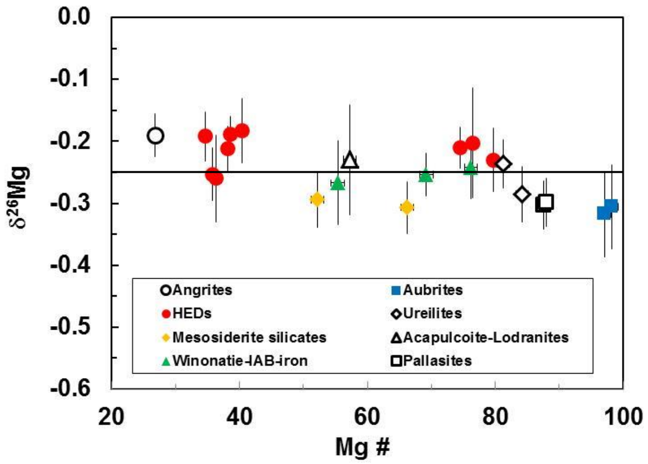

Fig. 1 Variation of δ^{26}Mg with Mg# of meteorites studied here. The solid line represents the average δ^{26}Mg of -0.25‰ for the Earth [11]. These meteorites include angrite (D′orbigny), HEDs (Diogenites: Bilanga, Johnstown, and Tatahouine; and Eucrites: Sioux county, Béréba, Juvinas, Bouvante, Ibitira, and Pasamonte), mesosiderite silicates (Estherville and Crab orchard), Winonaite-IAB-iron group (Campo del Cielo, Landes, and Winona), aubrites (Peña Blanca Spring and Bishopville), ureilites (Goalpara and Novo-Urei), acapulcoite-lodranites (Acapulco), and pallasites (Brahin and Mount Vernon).

Discussion and conclusion: Fig. 1 shows limited Mg isotope variations within most achondrite groups. Within uncertainties, there are only small unresolvable variations between few groups, in which D′Orbigny (angrite) and some HEDs are slightly enriched in heavy Mg isotopes compared to aubrites and pallasite meteorites. These isotopic variations show a significant trend with chemical compositions of these achondrites (Mg#s, Fig. 1). On the other hand, theoretical and experimental studies of terrestrial rocks and minerals have shown that clinopyroxene is slightly heavier than orthopyroxene and olivine in Mg isotopes [e.g., 15-17]. Therefore, the small Mg isotopic variations between these achondrite groups can be caused by different mineralogical sources of their parent bodies.

Isotopic heterogeneity in some groups of achondrites, as seen for O, Z, Fe, could reflect rapid mixing of the interior sources, primary source heterogeneity and/or heterogeneities produced by magmatic differentiation of parent bodies [e.g.,18-20]. However, Mg isotopic compositions of meteorites from different groups of achondrites display no significant Mg isotope fractionation within each individual group, different from the one observed for other isotopes [18-20].

The average Mg isotopic composition of achondrites by using the MgO-weighted average δ^{26}Mg value of these samples is -0.26 ± 0.05‰ (2SD, n = 22), which is between the average of HEDs reported by Wiechert and Halliday [7] (0.00 ± 0.06‰ (2SE, n = 9)) and the average of pallasites reported by Chakrabarti and Jacobsen [8] (-0.54 ± 0.04‰ (2SE, n = 7)). The MgO-weighted average isotopic composition of achondrites estimated here is indistinguishable from those of the Earth (δ^{26}Mg = -0.25 ± 0.07‰; 2SD, n = 139), chondrites (δ^{26}Mg = -0.28 ± 0.06‰; 2SD, n = 38), and the Moon (δ^{26}Mg = -0.26 ± 0.16‰) measured in the same laboratory [11, 13]. This result agrees well with the homogeneous chondritic Mg isotope composition of inner solar system concluded by Chakrabarti and Jacobsen [8].

The similar and chondritic Mg isotopic composition of achondrites, the Moon and the Earth further support the homogeneity of Mg stable isotopes in the early solar system and rules out the possibility of physical separation and sorting processes of isotopically differentiated chondrules and CAIs in the planetary accretion disk processes.

References: [1] Mittlefehldt D. W. (2004) Achondrites. *in Treatise on Gesochemsitry, vol1*, 291-324. [2] Paniello R. C. et al. (2012) *GCA 86*, 76-87. [3] Fitoussi C. et al. (2009) *EPSL 287*, 77-85. [4] Poitrasson F. et al. (2005) *EPSL 234*, 151-164. [5] Magna T. et al. (2014) *GCA 125*, 131-145. [6] Norman M.D. et al. (2006) *Geophys. Res. Lett. 33*, L15202. [7] Wiechert U. and Halliday A.N. (2007) *EPSL, 256*, 360-371. [8] Chakrabarti R. and Jacobsen S.B. (2010) *EPSL, 293*, 349-358. [9] Teng F.-Z. et al. (2007) *EPSL 261*, 84-92. [10] Yang W. et al. (2009) *EPSL 288*, 475-482. [11] Teng F.-Z. et al. (2010) *GCA, 74*, 4150-4166. [12] Ling M.-X. et al. (2011) *Rapid Commun. Mass Spectrom. 25*, 2828-2836. [13] Sedaghatpour F. et al. (2013) *GCA 120*, 1-16. [14] Young E. D. and Galy A. (2004) *Rev. Mineral. Geochem. 55*, 197-230. [15] Young E.D. et al. (2009) *EPSL, 288*, 524-533. [16] Liu S.-A. et al. (2011) *EPSL 308*, 131-140. [17] Schauble E. A. (2011) *GCA 75*, 844-869. [18] Wiechert U. H. et al. (2004) *EPSL 221*, 373-382. [19] Paniello R. C. et al. (2012) *GCA 86*, 76-87. [20] Wang K. et al. (2012) *GCA 89*, 31-45.