CALCIUM ISOTOPIC VARIATIONS IN CHONDRITES: IMPLICATIONS FOR PLANETARY ISOTOPE COMPOSITIONS. S. Huang[1] and S. B. Jacobsen[1], [1]Department of Earth and Planetary Sciences, Harvard University (huang17@fas.harvard.edu; jacobsen@neodymium.harvard.edu).

Introduction: Chondrites are primitive materials of the inner Solar System in that they escaped the planetary differentiation processes. Their isotope and chemical compositions can be used to re-construct the evolution of the early Solar System, and to constrain the bulk composition of Earth and other planets [e.g. 1, 2]. It has been well established that different chondrite groups are characterized by distinct oxygen isotope compositions [3]. Previous studies also reported mass-dependent isotope variations of Ca among different chondritic groups [4]. In contrast, within analytical uncertainty, Mg [5-6], Fe [7] and Si [8-9] isotopes are homogeneous among different chondrite groups, with the possible exception of Si isotopes in enstatite chondrites. Since Ca is the only major element in addition to O that show substantial isotope variations in chondrites, we report further Ca isotope measurements of three groups of chondrites (carbonaceous, ordinary and enstatite chondrites) using the established techniques reported in [10-11]. Such data are needed to better understand the relationship between (i) mass-dependent isotopic variations (δ-values), (ii) mass-independent isotopic variations (ε-values; $\Delta^{17}O$) and (iii) chemical compositions within the chondrites. This information is essential for being able to properly select initial isotope compositions for modeling planetary reservoir evolution.

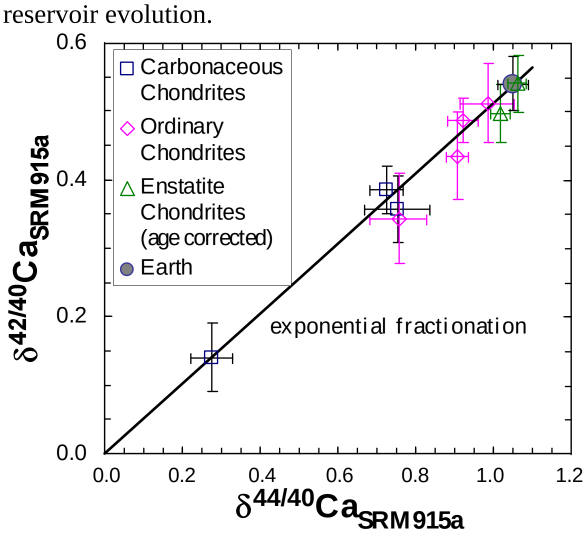

Fig. 1 $\delta^{44/40}Ca$ vs. $\delta^{42/40}Ca$ for three chondrite groups corrected for their radiogenic ^{40}Ca using literature K/Ca ratios. This correction is in all cases < 0.1‰. All chondrites plot on the exponential fractionation trend.

Results: After correction for the radiogenic ^{40}Ca ingrowth in the chondrites, all samples plot along the exponential fractionation trend in a three Ca isotope plot ($\delta^{44/40}Ca$ vs. $\delta^{42/40}Ca$) (Fig. 1). There are relatively large measurable $\delta^{44/40}Ca$ variations among the three chondritic groups. In detail, the enstatite chondrites have the highest $\delta^{44/40}Ca$, overlapping with the estimated value (1.05) for the upper mantle [10]. Carbonaceous chondrites have the lowest $\delta^{44/40}Ca$ among three chondritic groups, and Allende (CV3) has the lowest $\delta^{44/40}Ca$ (0.28±0.05) among all studied chondrites. Ordinary chondrites have $\delta^{44/40}Ca$ of 0.76 to 0.98, filling the gap between enstatite chondrites and carbonaceous chondrites (Fig. 1). Thus $\delta^{44/40}Ca$ decreases in the order of enstatite chondrites > ordinary chondrites > carbonaceous chondrites as was also observed by Simon and DePaolo [4].

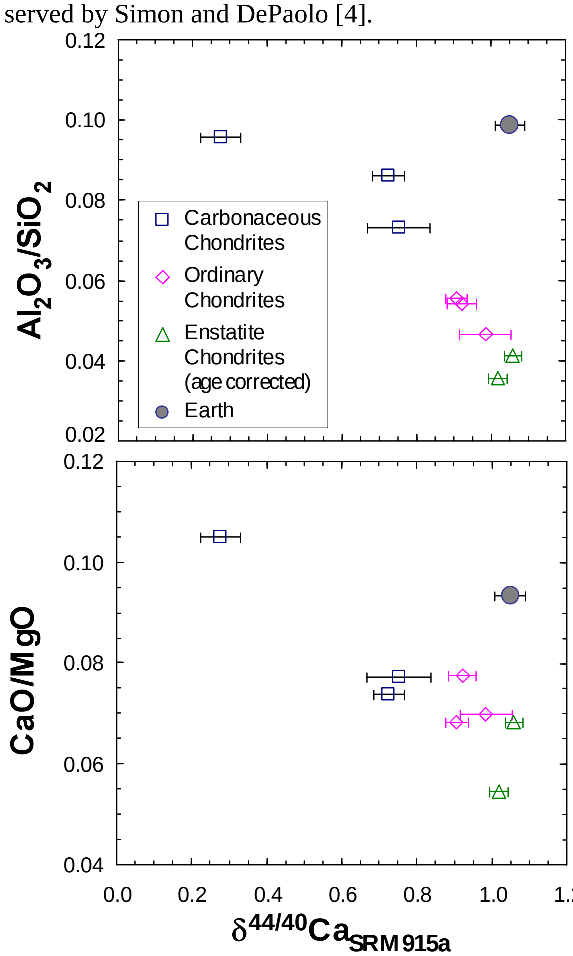

Fig. 2 $\delta^{44/40}Ca$ vs. Al_2O_3/SiO_2 and CaO/MgO (both wt ratios) in three chondrite groups. Estimates of the bulk Earth are plotted for comparison.

Discussion: Chondrites form a positive Al/Si vs. Mg/Si trend: enstatite chondrites define the low-Al/Si and -Mg/Si end, carbonaceous chondrites define the high-Al/Si and -Mg/Si end, and ordinary chondrites fill the gap in between [e.g., 1, 12]. We note that the inter-group variations of Al/Si and Mg/Si among different chondrite groups mimic that of the $\delta^{44/40}$Ca variation. Specifically, three chondrite groups form negative trends in plots of $\delta^{44/40}$Ca vs. Al_2O_3/SiO_2 and CaO/MgO, both ratios of a refractory element over a volatile element (Fig. 2). Interestingly, the bulk Earth estimates do not plot on the chondrite trends or their extensions (Fig. 2). The $\delta^{44/40}$Ca vs. Al_2O_3/SiO_2 and CaO/MgO trends of chondrites may reflect different proportions of Ca-Al-rich inclusions (CAIs) in different chondrite groups. Consistent with this interpretation, Allende, with the lowest $\delta^{44/40}$Ca, is also characterized by a positive ^{48}Ca anomaly (Fig. 3), both distinctive features of CAIs [11]. In contrast, within error enstatite chondrite Abee has the same $\varepsilon^{48/44}$Ca as the Earth (Fig. 3).

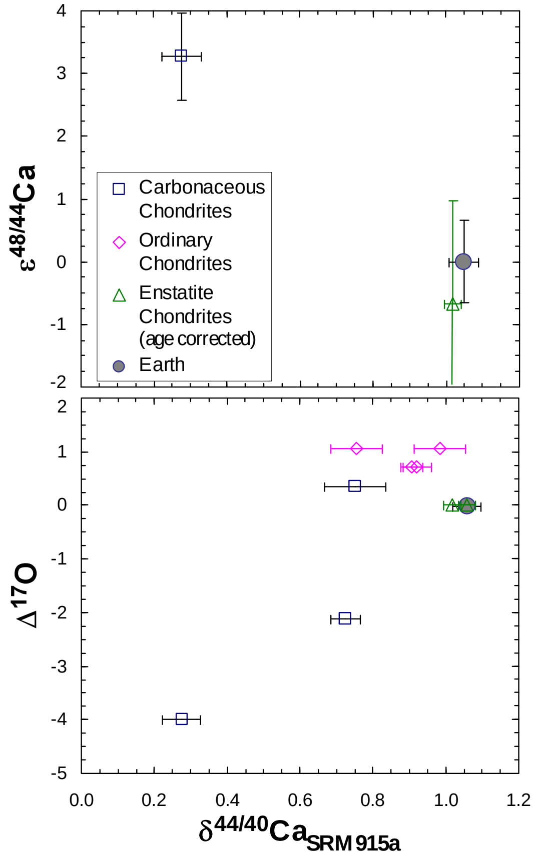

Fig. 3 $\delta^{44/40}$Ca vs. Δ^{17}O and $\varepsilon^{48/44}$Ca in chondrite groups.

A recent study [13] also reported that enstatite chondrites are the only chondrite group having the same Ti and Cr isotope compositions as the Earth. Compared to the Earth, both carbonaceous and ordinary chondrites show positive ε^{46}Ti, ε^{50}Ti and ε^{54}Cr anomalies, in part at least reflecting a contribution from CAIs. In summary, enstatite chondrites and the Earth have the same isotope compositions for all major and minor elements (O, Ca, Ti, Cr) which exhibit substantial isotopic variations among different chondritic groups. Si is the only exception in that enststite chondrities have lower δ^{30}Si compared to the estimate for the Earth's mantle [8-9] (Fig. 4). However, there is substantial Si in the metal phases in enstatite chondrites [14] and this Si is likely to have very low δ^{30}Si-values. Since all available δ^{30}Si data of enstatite chondrites are from EH chondrites with high metal contents, their measured δ^{30}Si may not neceraily reflect the isotope composition of the parental nebular reservoir.

In conclusion, the Earth and enstatite chondrites have essentially identical isotope compositions, suggesting they are both derived from the same parental nebular reservoir. The very different chemical compositions of Earth and enstatite chondrites must then be due to different chemical processes operating during their formation.

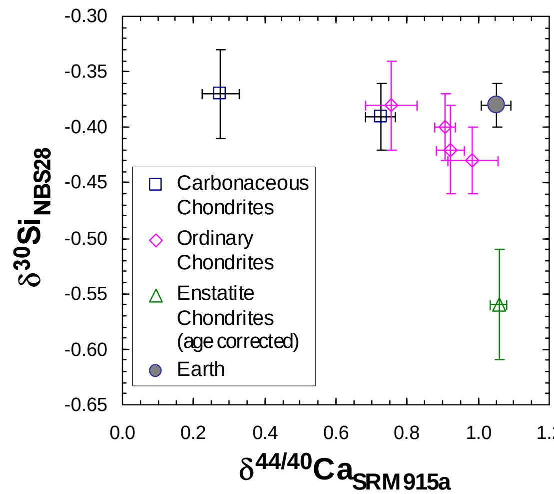

Fig. 4 $\delta^{44/40}$Ca vs. δ^{30}Si in three chondrite groups. Estimates of the bulk Earth are plotted for comparison.

References: [1] Jagoutz et al. (1979) *LPSC 10*, 2031-2050. [2] Jacobsen and Wasserburg (1980) *EPSL 50*, 139-155. [3] Clayton (2003) *Space Sci. Rev. 106*, 19-32. [4] Simon and DePaolo (2010) *EPSL 289*, 457-466. [5] Chakrabarti and Jacobsen (2010) *EPSL 293*, 349-358. [6] Teng et al. (2010) *GCA 74*, 4150-4166. [7] Dauphas et al. (2009) *EPSL 288*, 255-267. [8] Fitoussi et al. (2009) *EPSL 287*, 77-85. [9] Chakrabarti and Jacobsen (2010) *GCA 74*, 6921-6933. [10] Huang S. et al. (2010) *EPSL 292*, 337-344. [11] Huang et al. (2012) *GCA 77*, 252-265; [12] Drake and Righter (2002) *Nature 416*, 39-44. [13] Trinquier et al. (2009) *Science 324*, 374-376. [14] Ringwood (1961) *GCA 25*, 1-13.