ISOTOPIC FRACTIONATION OF SILICON DURING TERRESTRIAL CORE FORMATION. R. B. Georg[1,2] and A. N. Halliday[2], [1]ETH Zurich, Department of Earth Science, Institute for Isotope Geology & Mineral Resources (Clausiusstr. 25, CH-8092 Zurich, Switzerland, georg@erdw.ethz.ch), [2]University of Oxford, Department of Earth Sciences (Parks Road OX1 3PR, Oxford, United Kingdom, alexh@earth.ox.ac.uk).

Introduction: It has long been proposed that the Earth's core must contain significant quantities of light elements, such as H, C, Si, S and K [1]. The high Mg/Si of the terrestrial mantle has been used to argue that Si in particular is an important component in the core [2-4]. Recent estimates indicate that it contains as much as 5-7wt%, which compares with 21wt% Si in the primitive mantle [5, 6]. The partitioning of Si into the metallic core should yield isotopic effects because of differences in bonding of Si between metals and silicates [7]. Silicon partitioning into metal is thought to be a high-pressure, high-temperature process which would not be expected on smaller objects, such as Vesta and Mars [6, 8].

By comparing precise Si isotope compositions for different silicate reservoirs of the solar system as sampled by chondrites, basaltic achondrites thought to come from Vesta and Mars, and basaltic rocks from the Moon and the Earth's mantle we have found isotopic evidence for Si partitioning into the Earth's core. The similar isotopic composition of bulk silicate Earth (BSE) and the Moon indicates that the partitioning of Si must have been completed before the giant impact caused the birth of the Moon.

Methods & Results: We analysed 44 meteoritic, lunar and terrestrial samples. All samples were carefully processed according to the procedures described elsewhere [9]. Silicon isotope data were acquired in high-resolution mode using the Nu1700 MC-ICP-MS (ETH Zurich) and are presented using the common δ-notation (relative to NBS-28).

All samples plot on a single mass-dependent fractionation line with a slope of $\delta^{29}Si=\delta^{30}Si \times 0.5178$, with no isotopic anomalies being detected (Figure 1). The mean $\delta^{30}Si$ ($\pm1\sigma_{SD}$) values of the silicate reservoirs are as follows: Carbonaceous chondrites (5): -0.58±0.05‰, Ordinary chondrites (6): -0.57±0.04‰, HED basaltic achondrites (6): -0.56±0.06‰, Martian meteorites (3): -0.59±0.05‰, Moon (4): -0.30±0.03‰ and bulk silicate earth (12): -0.38±0.06‰. The bulk meteoritic mean is identical to previous estimates [10], however, the range we have observed is an order of magnitude smaller, allowing us to constrain an average chondritic $\delta^{30}Si$ of -0.58±0.12‰ ($\pm2\sigma_{SD}$). The mean value for BSE is also in accord with previous estimates for the average BSE, normally given as -0.3‰ [11].

Discussion: By comparing the average isotopic composition of the different silicate reservoirs we found the BSE and Moon to be significantly offset from the average chondritic isotopic composition. However, the Si isotopic composition of basaltic achondrites thought to come from Vesta and Mars are identical to the average chondritic value, providing evidence that the early solar system was isotopically homogeneous for Si. Similar isotope effects and early solar system homogeneity have been reported for Fe isotopes, inasmuch as the Moon and BSE are offset from Mars and Vesta, which are in turn identical to the average chondritic value [12-14].

There are two obvious explanations for these data: (i) high-pressure fractionation of Si into the Earth's core, and (ii) partial loss during high-temperature evaporation/condensation processes related to the Moon-forming Giant Impact.

Partitioning of Si into the Earth's core is thought to be a high pressure, high-temperature effect [8] and based on theoretical constraints this process should lead to an enrichment of heavy Si isotopes within the mantle, as the Si-O bonds in silicates are "stiffer" compared to weak metallic bonds between Si and Fe [7]. Similar isotopic effects are not expected for Mars or Vesta, simply because those bodies are too small. A high pressure core formation explanation for the heavy Fe isotope composition of the BSE is more difficult to explain but may relate to high-pressure perovskite formation. Perovskite-metal fractionation [15] is thought to increase the O fugacity within the early mantle [6], leading to oxidation and the formation ferric Fe, which has been shown to result in heavy Fe isotope compositions within the mantle [16].

The second explanation for the isotope effects of Fe and Si is partial loss caused by evaporation and condensation during the giant impact which formed the Moon. The Earth is enriched in highly refactory elements [17], which is sometimes considered to be caused by losses during impact erosion. However, this explanation is hard to reconcile with Mg and Li isotope data which show no difference between mantle-derived silicates from the Earth, Moon, Mars or Vesta [18-20], despite similar half-mass condensation temperatures [21] for Li, Mg, Si and Fe. Therefore, it appears that (i), partitoning during core formation, is the most plausible explanation for the Si isotope data.

This however, leads to the question of why the Moon and BSE are quite similar in terms of Fe and Si isotope compositions. Based on our meteorite data, it is logical to assume that the early Earth and Theia, the relatively small body that collided with the early Earth to form the Moon, must both have had chondritic bulk compositions for Si and Fe. As a consequence of core formation both elements became isotopically enriched in the BSE. To transfer the BSE-like isotope composition of Fe and Si into the Moon is most readily explained by equilibration of the vapor cloud from which the Moon condensed with the proto-Earth as recently proposed by Pahleven & Stevenson [22] on the basis of O isotopes.

Conclusions: The new high precision Si isotope data for different silicate reservoirs within the solar system show that chondrites, Mars and Vesta are isotopically similar, whereas Earth and Moon are offset. This offset can be best explained by high-pressure core formation causing Si partitioning into the Earth's core with concomitant isotopic fractionation.

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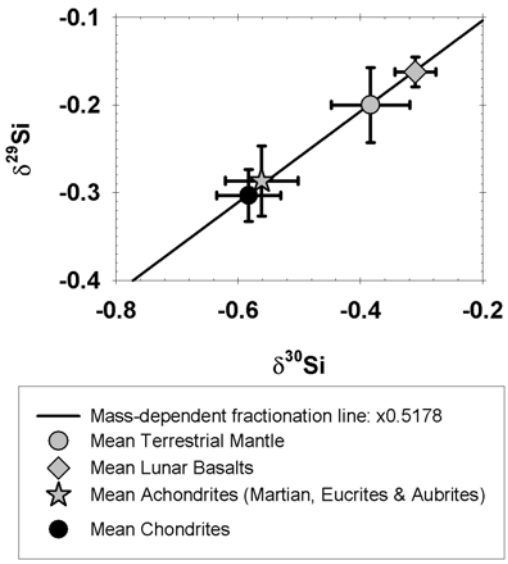

Figure 1: Three isotope plot to illustrate the similarities and differences between reservoirs, given as group means $\pm 1\sigma_{SD}$. All data plot on a single mass dependent fractionation line consistent with a single homogeneous inner solar system Si isotopic reservoir.