SI ISOTOPE CONSTRAINTS ON THE MOON-FORMING IMPACT. C. Fitoussi[1], B. Bourdon[1], K. Pahlevan[2], R. Wieler[1], [1]Institue of Isotope Geochemistry and Mineral Resources ETH Zurich, Clausiusstrasse 25, 8092 Zurich, Switzerland, [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125 USA.

Introduction: The formation of the Moon by a giant impact could have significantly affected the isotope composition of moderately volatile elements such as silicon, as it should have resulted in a massive vaporization of the precursors of the lunar material. Consequently, high precision analysis of silicon isotopes in lunar rocks, compared with terrestrial rocks and chondrites, can potentially provide insights into the Moon-forming processes and might also yield information on the nature of the lunar impactor.

Samples and methods: The silicon isotope compositions of several high- and low-Ti mare basalts were measured with the high resolution MC-ICPMS NuPlasma 1700 to high precision (0.04‰ in δ^{30}Si, 2SE). The mass bias correction is done by sample-standard bracketing and isotope compositions are reported relative to the NBS28 standard. The samples were treated by alkaline fusion for digestion, followed by ion-exchange chromatography using 1 mL resin of BioRad AG50W-X8.

Results: The δ^{30}Si values of the analyzed lunar samples range from -0.33 to -0.27‰ with an average of -0.30±0.05‰ (2SD). This can be compared with previously measured terrestrial samples with a mean δ^{30}Si of -0.28±0.06‰ (2SD) [1]. At present, no difference in the silicon isotope composition of the silicate Earth and Moon can be resolved, while the isotopic composition of both reservoirs is distinct from the chondrites.

Discussion: Dynamic simulations of the giant impact on Earth that formed the Moon [2] conclude that the major proportion of the material injected into the proto-lunar disk is sourced from the silicate mantle of the impactor. Given the size of the impactor (typically Mars-sized), it was most likely a differentiated object. Based on measurements of the Si content in the metal phase of iron meteorites [3], it is reasonable to assume that the Si budget of the impactor was dominated by the mantle. There are two ways to explain the silicon data for the Moon.

(i) After the giant impact, the material in the proto-lunar disk is assumed to have a Si isotope composition which is a mixture of that of the impactor and that of the proto-Earth's mantle. The Si isotope composition of the impactor can be akin to that of achondrites or of chondrites [1,4] while the δ^{30}Si of the Earth's mantle at the time of the impact is well represented by the measured modern value, given that most of the Earth's core must have formed before the Moon-forming giant impact [5] and only ~10 percent of the mass of Earth mantle was contributed by the impactor. This implies that, at the time of the giant impact, the Earth's mantle already had its heavier-than-chondritic Si isotope composition.

The silicon isotope composition of the Moon-forming impactor is not known. That there is an observed isotopic difference between the chondrites and the silicate Earth [1,4] suggests that the Moon-forming impactor may have been distinct from the silicate Earth as well. It is also possible that the lunar isotopic composition reflects that of the Moon-forming impactor, which, by chance, had an Earth-like isotopic composition. However, such an interpretation requires that the impactor have an isotopic composition that falls outside of the range defined by the chondrites. In addition, such a model is, at present, not testable.

Alternatively, to account for the final terrestrial value of the measured Si isotope composition of the lunar samples, the material in the protolunar disk could have undergone evaporative loss of SiO, which would have resulted in greater δ^{30}Si values in the lunar material. However, the mean molecular weight of silicate vapors (μ = 40 amu) is generally high enough for these gases to be bound to the Earth's gravitational field, even at temperatures of several thousand degrees [6].

(ii) In order to account for the similarity of several other isotope systems such as O [7], W [8], and Cr [9] between Earth and Moon silicate phases, a model involving isotope equilibration through turbulent fluid exchange between the terrestrial magma ocean and the surrounding melt-vapor proto-lunar disk following the giant impact has been suggested [10]. Since the isotopic homogeneity of the Earth-Moon system includes both volatile and refractory elements, turbulent exchange may have involved both the silicate vapor and the suspended liquid droplets, isotopically homogenizing all elements irrespective of their volatility. In such a scenario, the terrestrial value of the silicon isotope composition of lunar samples can be explained through inheritance from Earth's mantle.

In addition to isotope equilibration leading to the inheritance of the terrestrial mantle composition, vaporization of silicates in the proto-lunar disk could have produced Si isotope compositions distinct from the terrestrial value, because the Si isotopic composition of the liquid and vapor – even at temperatures of thousands of degrees – can be significantly fractionated. Depending on the amount of phase separation that occurs, this scenario can result in a lunar Si isotope composition that is lighter than the terrestrial value [11]. This is not observed. By taking the terrestrial value as the starting Si isotope composition in the terrestrial magma ocean, and assuming liquid-vapor fractionation, the currently achievable analytical precision of the measurement provides a constraint on the extent of liquid rainout in the post giant-impact silicate vapor atmosphere of Earth [11].

References::

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