

THE OXYGEN ISOTOPE COMPOSITION OF THE MOON: IMPLICATIONS FOR PLANET FORMATION. U. Wiechert¹, ¹Institute for Isotope Geology and Mineral Resources, ETH-Zentrum NO, 8092 Zürich, Switzerland. E-mail address: wiechert@erdw.ethz.ch

Introduction: The Moon is widely considered to have formed during a collision between the proto-Earth and a Mars-sized planet (named Theia). Assuming this model to be correct the Moon was formed from materials from the proto-Earth, Theia and any additional material added later. Oxygen isotope variations in differentiated planetary bodies like the Earth, Mars or the HED parent body are largely mass-dependent, i.e. the data define a characteristic line with a slope of ~ 0.52 in a graph of ^{17}O vs. ^{18}O . In general, different parent bodies define distinct parallel trends reflecting different bulk compositions for the parent bodies. The differences are usually expressed as ^{17}O , which is the deviation from the mass-dependent fractionation trend defined by terrestrial samples in per mil ^{17}O . The first oxygen isotope data for lunar samples published by Clayton and Mayeda [1] fell along a linear array overlapping with the terrestrial samples. However, these early oxygen isotope data for the Moon have a large range of $\sim 0.3\%$ which may reflect some isotopic heterogeneity of the Moon. Therefore, lunar samples have been re-investigated with a high precision CO_2 laser fluorination method [2].

Results: With this method the oxygen isotopic composition of 31 lunar samples averaged $^{17}\text{O}=0 \pm 0.005\%$ (3 sigma standard error of the mean). Even at this very high precision no resolvable difference between the Earth and Moon is detectable despite the fact that oxygen isotopes are very heterogeneous in the solar system. The simplest explanation for an identical oxygen isotope composition would be that the proportions of material from the impactor and the proto-Earth were identical in the Earth and Moon. Most giant impact simulations indicate that the majority of the material that formed the Moon originated from Theia rather than the proto-Earth. Given that the most of the Earth was already built by the time of the Giant Impact the proportions cannot be the same. The only explanation that is consistent with Giant Impact simulations is that Theia and the proto-Earth had identical or very similar oxygen isotope compositions.

Discussion: If Theia and the Earth formed from raw materials that were identical in oxygen isotopes, why then are they so different in terms of their chemical composition? For example the Moon and Earth have very different depletion in volatiles and the lunar mantle has a high FeO content. Some of this could result from the giant impact or differentiation of the

proto-Earth, Theia, the Moon, or the present Earth. Comparing the Moon with other planetary bodies such as Mars or the HED parent body indicates that the Fe content of the lunar mantle is “normal” and the Fe content of the terrestrial mantle is unusually low. Therefore, the difference might be completely related to more protracted and extensive terrestrial core formation, but this is far from settled.

Another striking difference between the Earth and Moon is the strong depletion of the Moon in volatile elements compared with the Earth. Potassium isotopes have been used to argue that the depletion of alkalis and other volatiles in the inner solar system must have occurred during the condensation of precursor dust from a hot stage of the solar nebula [3]. This seems to favor an origin of Theia from material with a higher degree of depletion in volatiles. However, recently it has been argued that the Moon lost volatiles during its accretion [4]. The latter is supported by the timing of the moderate volatile element loss for the Moon >10 Myrs after cooling of the solar nebula [5]. This is inconsistent with models that assume a very early volatile loss. In fact, it supports the view that moderately volatile elements have been lost during accretion. Therefore, the oxygen isotope composition of the Moon provide evidence that objects as different as the Moon and Earth have been made out of an identical mix of material. The mechanism of volatile element loss without corresponding mass-dependent fractionation is the subject of ongoing research.

References: [1] Clayton R. N. and Mayeda T. (1975) Proc. Lunar Sci Conf XI, 1761. [2] Wiechert U. et al. (2001) *Science*, 294, 345–348. [3] Humayun M. and Clayton R. N. (1995) *GCA*, 59, 2131–2151. [4] Lodders K. (2000) *Space Sci Rev*, 92, 341. [5] Halliday A. N. and Porcelli D. (2001) *EPSL*, 192, 545–559.