Half-life and initial Solar System abundance of ^{146}Sm determined from the oldest andesitic meteorite

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Introduction: ^{146}Sm-^{142}Nd radioactive systematics can provide constraints on the timing of early differentiation processes on Earth, Moon, and Mars. However, the uncertainties related to the initial abundance and half-life (103 [1,2] or 68 Ma [3]) of the extinct isotope ^{146}Sm impede the interpretation of the ^{146}Sm-^{142}Nd systematics. Here, we apply the short-lived ^{26}Al-^{26}Mg, ^{146}Sm-^{142}Nd, and long-lived ^{147}Sm-^{143}Sm chronometers to the oldest known andesitic meteorite and volcanical rock, Erg Chech 002 (EC 002) [4]. A robust crystallization age for EC 002 is constrained by ^{26}Al-^{26}Mg and ^{147}Sm-^{143}Nd mineral isochrons. Literature $^{146}Sm/^{144}Sm$ data of CAIs and asteroidal and planetary bodies are then combined with the $^{146}Sm/^{144}Sm$ value of EC 002 to obtain the best fit value for the half-life of ^{146}Sm. Finally, the ^{146}Sm-^{142}Nd isochron of EC 002 is used to deduce a precise and best estimate for the initial $^{146}Sm/^{144}Sm$ ratio of the Solar System.

Material and Methods: A mass of ~4 g of EC 002 was crushed in an agate mortar and several mineral and bulk-rock fractions were separated from that. All the fractions have been passed through columns with ion exchange and specific resins in several steps to discard the matrix and purify solutions for Sm, Nd and Mg. Stable Sm, Nd and radiogenic Nd isotopic ratios were measured using TIMS. The $^{27}Al/^{24}Mg$ and Mg isotopic compositions were measured using ICP-MS and MC-ICP-MS, respectively.

Results and Discussion: The linear correction between $\delta^{26}Mg^*$ and $^{27}Al/^{24}Mg$ defines an initial $^{26}Mg/^{24}Mg$ ratio ($\delta^{26}Mg^*_0$) of -0.009±0.005 ‰ (2σ) and a slope corresponding to a $(^{26}Al/^{27}Al)_0$ of (8.89±0.09) $\times 10^{-6}$ which translates to an age of 1.80±0.01 Myr after CAIs formation. This age is ~450,000 years older than the in-situ ion microprobe Al-Mg age from Barrat et al. [5]. The two isochrons most likely date two different events since Mg in plagioclase diffused much faster than in pyroxene and the core of the plagioclase crystal analyzed by ion microprobe is probably not a closed system for Mg diffusion. If this hypothesis is correct, the MC-ICP-MS ^{26}Al age would be closer to the crystallization age. EC 002 displays a $\mu^{148}Nd$ nucleosynthetic composition of 12.0±3.6 (2SD) parts per million (ppm) which is distinctly lower than any Carbonaceous meteorites and falls within the Non-carbonaceous (NC) region, suggesting that the parent body of EC 002 is likely derived from the NC meteorite reservoir, in agreement with its negative Tm anomaly [5]. The ^{147}Sm-^{143}Nd isochron returns an initial $^{143}Nd/^{144}Nd$ ratio of 0.50679$\pm$0.00018 and defines a ^{147}Sm-^{143}Nd age of 4521±152 Ma. All $^{144}Sm/^{144}Nd$ and $^{142}Nd/^{144}Nd$ ratios of EC 002 define a regression line with an initial $^{146}Sm/^{144}Sm$ ratio of 0.00830±0.00032. Using the coupled fit lines of crystallization ages from other robust dating systems (^{147}Sm-^{143}Nd, Pu-Xe, Pb-Pb, and ^{26}Al-^{26}Mg) and $^{146}Sm/^{144}Sm$ ratios of CAIs, asteroidal and planetary samples, the half-life of ^{146}Sm is modeled to be 102±9 Ma [4]. This modelling with natural samples provides robust support for the experimentally-determined ^{146}Sm half-life value of 103 Ma, which is 35 Myr longer than the most recent determination [3]. The 103 Ma half-life confirmed here eliminates a large source of uncertainty on age determinations of the differentiation of the early mantle and lunar magma ocean. By combining the ^{26}Al-^{26}Mg crystallization age of EC 002 with the $^{146}Sm/^{144}Sm$ abundance recorded by the same mineral fractions, we deduced an initial $^{146}Sm/^{144}Sm$ for the Solar System of 0.00840±0.00032, which is the most reliable and precise estimate to use for ^{146}Sm-^{142}Nd chronology [4].

Conclusion: The Al-Mg systematics confirm that EC 002 is the oldest known andesitic meteorite as well as the oldest volcanical rock, with a formation age of 1.80±0.01 Myr after the Solar System formation. Stable Nd isotopic anomalies indicate that the parent body of EC 002 formed within the NC Reservoir. The most consistent half-life of ^{146}Sm is 103 Ma from which we derive an initial $^{146}Sm/^{144}Sm$ ratio of the Solar System of 0.0084±0.00032. In association with its large recovered mass (~32 kg), abundant coarse mineral grains, and trace element-enriched composition, EC 002 represents the best anchor for ^{146}Sm-^{142}Nd systematics in planetary materials, and possibly for other short-lived radioactive decay systems.

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