Lunar Sm/Nd. First, a combined Lu/Hf and Sm-Nd isotope study on lunar samples demonstrated that the lunar Hf-Nd isotope record, after correction for neutron capture-induced Hf isotope variations, requires a bulk Moon having chondritic Sm/Nd and Lu/Hf [8]. Second, the lunar and shergottite 146Sm/144Nd isochrons intersect at a chondritic Sm/Nd, implying that both bodies are characterized by a common bulk Sm/Nd similar to that of chondrites, consistent with the absence of large Sm/Nd fractionations in meteorites. The bulk 142Nd/144Nd of the Moon and Mars can, therefore, be obtained from the 142Nd/144Nd of the lunar and shergottite isochrons at a chondritic Sm/Nd. For both the Moon and Mars this value is ~7-8 ppm below the 142Nd/144Nd of the modern terrestrial mantle.

Given the strong genetic and compositional link between the Earth’s mantle and the Moon, the 147Sm/144Nd and 142Nd/144Nd inferred for the Moon also represent the composition of the bulk silicate Earth. This conclusion is consistent with a recent Nd isotope study on enstatite chondrites, which argued that the 142Nd/144Nd difference between the accessible Earth and the bulk silicate Earth may be only ~10 ppm [13].

Introduction: One of the most fundamental assumptions in modern geochemistry is that the bulk composition of the Earth and other terrestrial planets is chondritic for refractory elements [1]. However, based on the finding that chondrites exhibit a 142Nd deficit relative to the modern terrestrial mantle [2], the paradigm of a ‘chondritic’ Earth has been challenged [3].

While the 142Nd deficit in chondrites may reflect a very early Sm/Nd fractionation in the silicate Earth [2, 4], Caro et al. [3] argued that the common 142Nd excess of the Earth, Moon and Mars relative to chondrites is unlikely to result from an early differentiation within these bodies. They argued that this more likely reflects superchondritic Sm/Nd in the Earth, Moon, and Mars, which could be due to accretion from non-chondritic material or erosion of early-formed crust [3, 5-7].

Here we show that the 146Sm-142Nd data are inconsistent with superchondritic Sm/Nd in the Earth, Moon and Mars but are best explained by chondritic Sm/Nd in these bodies. The inferred bulk 142Nd/144Nd of these bodies is lower than that of the modern terrestrial mantle, but slightly elevated compared to ordinary chondrites. We show that these 142Nd variations are nucleosynthetic in origin and consistent with a heterogeneous distribution of s- and p-process Nd isotopes.

146Sm-142Nd systematics: 146Sm-142Nd isochrons for Moon and Mars. Caro et al. [3] observed that the 146Sm-142Nd isochrons of the lunar and martian mantles intersect at a higher-than-chondritic 147Sm/144Nd and at the 142Nd/144Nd of the modern terrestrial mantle. They argued that this point of intersection must reflect a common, superchondritic bulk composition of the Earth, Moon and Mars. However, re-examining the lunar and martian 146Sm-142Nd systematics reveals that the lunar and shergottite isochrons do not intersect at a superchondritic Sm/Nd, but rather intersect almost exactly at the chondritic 146Sm/144Nd, i.e., the expected bulk composition of Moon and Mars (Fig. 1). The proposed superchondritic composition of the Earth, Moon and Mars—termed ‘SCHEM’ [5]—plots off both isochrons and does not seem to provide a viable composition for the Moon and Mars.

Bulk Sm/Nd and 142Nd/144Nd of the Earth, Moon and Mars. Two lines of evidence suggest that both the Moon and Mars are characterized by chondritic Sm/Nd. First, a combined Lu-Hf and Sm-Nd isotope study on lunar samples demonstrated that the lunar Hf-Nd isotope record, after correction for neutron capture-induced Hf isotope variations, requires a bulk Moon having chondritic Sm/Nd and Lu/Hf [8]. Second, the lunar and shergottite 146Sm/144Nd isochrons intersect at a chondritic Sm/Nd, implying that both bodies are characterized by a common bulk Sm/Nd similar to that of chondrites, consistent with the absence of large Sm/Nd fractionations in meteorites. The bulk 142Nd/144Nd of the Moon and Mars can, therefore, be obtained from the 142Nd/144Nd of the lunar and shergottite isochrons at a chondritic Sm/Nd. For both the Moon and Mars this value is ~7-8 ppm below the 142Nd/144Nd of the modern terrestrial mantle.

Given the strong genetic and compositional link between the Earth’s mantle and the Moon, the 147Sm/144Nd and 142Nd/144Nd inferred for the Moon also represent the composition of the bulk silicate Earth. This conclusion is consistent with a recent Nd isotope study on enstatite chondrites, which argued that the 142Nd/144Nd difference between the accessible Earth and the bulk silicate Earth may be only ~10 ppm [13].

![Figure 1](image-url)
Chondrites exhibit a broad inverse correlation between $\varepsilon^{142}$Nd and $\varepsilon^{148}$Nd, which is broadly consistent with the $^{142}$Nd/$^{144}$Nd co-variation expected from a heterogeneous distribution of s-process isotopes (Fig. 2) [15]. An $\varepsilon^{142}$Nd-$\varepsilon^{148}$Nd correlation line through all the chondrite data corresponds to $\varepsilon^{142}$Nd~$\approx$-0.2 at $\varepsilon^{148}$Nd=0, which was interpreted to indicate that the elevated $^{142}$Nd/$^{144}$Nd of the accessible Earth compared to ordinary chondrites cannot be nucleosynthetic in origin [4, 15]. However, the mean compositions of enstatite, ordinary and carbonaceous chondrites plot on an $\varepsilon^{142}$Nd-$\varepsilon^{148}$Nd correlation line whose slope is steeper than that predicted for a heterogeneous distribution of s-process isotopes, but is consistent with coupled p- and s-process variations (Fig. 2).

![Fig. 2: $\varepsilon^{142}$Nd vs. $\varepsilon^{148}$Nd for chondrites. Data from [2, 4, 13, 14]. Solid line is a mixing line between a s-process component and terrestrial Nd characterized by a small $^{142}$Nd deficit. Dash-dotted line is a mixing line for coupled s- and p-process variability. Mixing lines calculated using the model of [16].](image)

Fig. 3 shows that the different $\varepsilon^{144}$Sm and $\varepsilon^{142}$Nd of chondrites are consistent with a heterogeneous distribution of p-process isotopes [4, 14]. The FUN CAI C1 with its large $^{142}$Sm excess [17] also plots on this correlation line (not shown in Fig. 3). Examination of Fig. 3 also shows that the bulk $^{142}$Nd/$^{144}$Nd of the Earth, Moon and Mars deduced in the present study plots slightly above the p-process mixing line passing through the compositions of the different groups of chondrites. This slightly higher $^{142}$Nd/$^{144}$Nd is consistent with a small excess in s-process Nd compared to ordinary chondrites. This small s-process variability would not induce any measurable $^{144}$Sm variations and would result in $^{142}$Nd and $^{144}$Sm anomalies of only ~10 ppm. This is consistent with the absence of resolvable Sm and $^{144}$Nd anomalies in ordinary chondrites [4, 14]. The better definition of any nucleosynthetic Nd and Sm isotope variability between chondrites and the terrestrial planets requires further investigation and most of all further improvement in the precision of Nd and Sm isotope measurements for the reliable detection of isotope anomalies smaller than ~10 ppm.

![Fig. 3: $\varepsilon^{142}$Nd vs. $\varepsilon^{144}$Sm for chondrites. Data sources as in Fig. 2. Solid lines represent mixing lines between s- and p-process components [16] and terrestrial Sm and Nd characterized by a small $^{142}$Nd deficit.](image)

**Conclusions:** Re-examining $^{142}$Nd data for lunar and martian samples reveals that the Earth, Moon and Mars are characterized by chondritic Sm/Nd, contrary to a recent proposal [3, 5]. The $^{142}$Nd/$^{144}$Nd of the Earth, Moon and Mars seems to be slightly lower than the value of the accessible silicate Earth, but more elevated than that of ordinary and carbonaceous chondrites. These $^{142}$Nd variations reflect a heterogeneous distribution of s- and p-process Nd and provide further evidence that the isotopic composition of the Earth cannot be reproduced by any combination of known meteorites [18]. $^{144}$Sm-$^{142}$Nd model ages for planetary differentiation should be calculated relative to a reservoir having chondritic Sm/Nd and a $^{142}$Nd/$^{144}$Nd ~7.8 ppm below that of the modern terrestrial mantle. This $^{142}$Nd difference probably is the result of an early differentiation within the silicate Earth ~4.5-4.45 Ga ago.

**References:**