^{142}Nd EVIDENCE FOR EARLY EARTH DIFFERENTIATION. M. Boyet[1], M. Rosing[2], J. Blichert-Toft[1], M. Storey[3], and F. Albarède[1] [1]Ecole Normale Supérieure, Lyon 69007 Lyon, France (albarede@ens-lyon.fr), [2]Geologisk Museum, Øster Voldgade 5-7, 1350 Copenhagen K, Denmark, [3]Danish Lithosphere Centre, Øster Voldgade 10, 1350 Copenhagen K, Denmark.

It is widely accepted that the lunar mantle went through a stage of generalized melting, the so-called magma ocean, which gave rise to the radial mineralogical layering of the planet. Similar evidence is totally missing on Earth for which no remnants of a very early crust are known and mostly indirect arguments. Because of the large Earth's radius, the amount of energy liberated by impactors and by core differentiation seems to have been sufficient to melt the terrestrial mantle down do several hundreds of kilometers [1-2]. The Earth's strong gravity field and the higher water contents of the terrestrial mantle restrict the presence of plagioclase on the liquidus of basaltic melts to shallower levels than on the Moon [3]. The petrological nature (anorthosite vs granite) of a buoyant crust blanketing a molten terrestrial upper mantle, and even its very existence, therefore remains problematic.

A strong argument in favor of early differentiation of the Earth would be the presence of extinct radioactivity anomalies in the mantle source of basalts. Chronometers with a half-life in the range of 1 to100 million years would fractionate in different mantle and crustal layers with parent/daughter ratios that would strongly depend on when the fractionation took place. Samarium-146 decays to ^{142}Nd with a half-life of 103 My and fractionation of Sm from Nd by crystallization of high-pressure silicates from a magma ocean, notably garnet, majorite, and perovskite, makes this chronometer a potential indicator of the presence of a terrestrial magma ocean. A sizeable deficit of ^{142}Nd relative to the bulk planetary composition formed during condensation has already been identified in various types of meteorites, notably chondrites, mesosiderites, and eucrites [4-7]. This deficit of about 250 ppm (or 2.5 epsilon units) corresponds to a ^{146}Sm/^{144}Sm ratio at the time the Solar System formed of about 0.0076 ± 0.0005, a value that is divided by two every 100 My.

Harper and Jacobsen [8] identified a measurable excess of ^{142}Nd in a metasediment from the Early Archean supracrustals of Isua, dated at ca. 3.8 Ga by a number of methods and concluded that the terrestrial mantle went through a stage of major differentiation about 4.50 ± 0.10 Gy ago. Although this measurement was replicated many times in the same laboratory, a single anomalous sample and the small amplitude of the anomaly at the limit of the analytical uncertainty (35 ppm) called for a confirmation that never came. A solution split from the same sample was analyzed by another group [9] with an ambiguous outcome, while the ongoing quest for identifying anomalies in other samples from Greenland [10-11] and the Early Archean terranes of Labrador proved unsuccessful [12].

The Isua supracrustal belt (ISB) is dominated by basaltic metavolcanic rocks with subordinate metasedimentary and ultramafic units of unknown derivation. In 1998-2000, we identified outcrops with remarkably well-preserved pillows and metagabbros. The ^{142}Nd abundance was measured in these rocks by MC-ICP-MS. From replicates of modern samples, which do not carry any ^{142}Nd anomaly, we estimate that by pooling replicates we can reach an external reproducibility of 10-15 ppm, i.e., a factor of two to three smaller than the anomaly reported by [8]. We also analyzed these samples for their ^{147}Sm-^{143}Nd and ^{176}Lu-^{176}Hf systematics. It was observed that leached and unleached samples can be distinguished in terms of their ^{143}Nd but not ^{142}Nd abundances. The Isua samples form two groups, a group of three samples with an anomaly of 30 ppm and the rest with no anomaly. Two of the three samples are medium-grained metagabbros taken a few meters apart on the same outcrop in the Western area. The third sample, a high magnesium metabasalt with preserved pillow morphology comes from the Southern area.

The samples form no statistically significant alignments in the ^{147}Sm-^{143}Nd isochron diagram. However, the three samples with a ^{142}Nd anomaly plot together on a statistically significant 3.78 ± 0.04 Ga ^{147}Sm-^{143}Nd isochron (MSWD = 0.6, $\varepsilon^{3.78}_{143\mathrm{Nd}}$ = 1.6 ± 1.0), which is within error of the ages most commonly accepted for the Isua protolith [13]. We consider these three samples to be the least transformed and, together with the remarkable similarity with Harper and Jacobsen's finding, lend strong support to the observed ^{142}Nd anomalies. We further conclude that the samples with no anomaly, which likely were of a nature similar to that of the anomalous samples, lost their ^{142}Nd excesses due to dilution upon fluid-mediated Nd exchange with early Archean lithologies derived from different mantle sources.

The present results provide strong evidence that Sm and Nd in the mantle source of some Isua mafic magmas were fractionated with respect to the bulk composition of the Earth very early in the history of the planet. Using a simple two-stage model in which the early fractionation episode that gave rise to the obser-

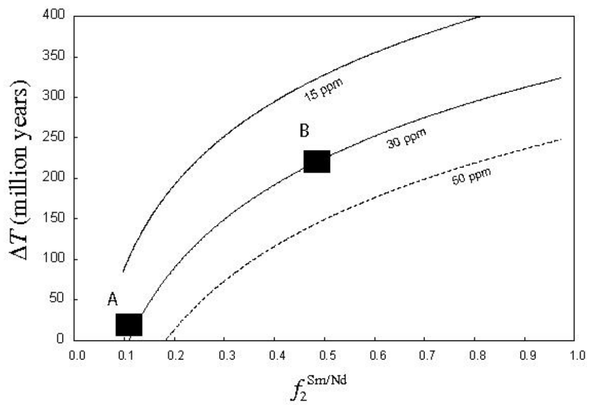

Figure 1: ^{142}Nd constraint on the age of the Earth differentiation. A. The Sm/Nd ratio is inferred from the ^{147}Sm-^{143}Nd systematics B. A 50 percent fractionation during differentiation is assumed.

ved Sm/Nd fractionation ends abruptly, we can estimate the interval ΔT between the formation of the Solar System and the differention of the terrestrial mantle. The $\varepsilon^0_{142\mathrm{Nd}}$ value of the Isua mantle source is 0.30 ± 0.07 and by compiling the literature values for meteorites we obtained a mean value of 0.0076 ± 0.0005 for the ^{146}Sm/^{144}Sm initial ratio. As Harper and Jacobsen, we used the $\varepsilon^{3.78}_{143\mathrm{Nd}}$ value at 3.78 Ga of our samples (+1.5) as provided by the ^{147}Sm-^{143}Nd isochron. The difference in initial ^{143}Nd isotope abundances of the present metagabbro samples and Harper and Jacobsen's metasediment sample may reflect either source effects or pervasive metasomatism at the time of emplacement. The inferred $f_2^{\mathrm{Sm/Nd}}$ value of about 0.08 ± 0.05 indicates a ΔT of about zero requiring that the major Sm/Nd fractionation of the mantle took place within few tens of millions of years of planetary accretion. Rapid mantle differentiation is consistent with all the most recent ^{182}Hf-^{182}W data on chondrites which suggest that the formation of the Earth's core took place within ca. 30 My of accretion [14-15]. Modelling the accretional heating of the Earth indicates that mantle melting and core extraction took place simultaneously [16]. An apparently simplistic but robust two-stage interpretation of the present $\varepsilon^0_{142\mathrm{Nd}}$ results for the mantle source of Isua metagabbros suggests that the Earth went through a molten stage during which the core separated from the silicate Earth and the molten mantle separated from a major geological reservoir with negative $f_2^{\mathrm{Sm/Nd}}$, which may be either an enriched lower mantle or a now destroyed protocrust [17-18].

Alternatively, a more complex history, such as one of those investigated by Harper and Jacobsen, may be required. In particular, mantle differentiation post-dating accretion by several hundred million years would have strongly affected the ^{147}Sm-^{143}Nd system while leaving the extinct ^{146}Sm-^{142}Nd system essentially unperturbed. In this case, the $f_2^{\mathrm{Sm/Nd}}$ value deduced from the initial $\varepsilon^{3.78}_{143\mathrm{Nd}}$ value of the isochron may not apply to ^{146}Sm-^{142}Nd. An upper limit of 50 percent Sm/Nd fractionation was chosen so as to fit the maximum ratio of Sm and Nd partition coefficients of any potential cumulate precipitating out of a magma ocean. Mantle-scale Sm/Nd fractionation can be controlled by either a major high-pressure mineral phase of the cumulate, such as Mg-perovskite, or by the presence of a relatively minor (typically <20 percent) but high-Sm/Nd phase, such as majorite or Ca-perovskite [19], present in the bulk cumulate.

[1] Wetherill G. W. (1976) *Proc. Lunar. Sci. Conf.* 7th, 3245-3257. [2] Kaula W.M. (1979) *JGR*, *84*, 999-1008. [3] Blichert-Toft J. et al. (2002) *EPSL, 204*, 167-181. [4] Prinzhofer A. et al. (1992) *GCA, 56*, 797-815. [5] Lugmair G.W., Galer J.G. (1992) *GCA, 56,* 1673-1694. [6] Nyquist L.E., et al. (1994) *Meteoritics 29,* 872-885. [7] Wadhwa M., Lugmair G.W. (1996) *GCA, 60*, 4889-4893. [8] Harper C.L., Jacobsen S.B. (1992) *Nature, 360*, 728-732. [9] Sharma M. et al. (1996) *GCA*, 60, 2037-2047 (1996). [10] McCulloch M.T. and Bennett V.C. (1993) *Lithos, 30,* 237-255. [11] Goldstein S.L., Galer S.J.G. (1992) *EOS, 73*, 323. [12] Regelous M., Collerson, K.D (1996) *GCA, 60,* 3513-3520. [13] Nutman A.P. et al. (1997) *Chem. Geol., 141,* 271-287. [14] Yin Q. et al. (2002) *Nature, 418,* 949-952 . [15] Kleine T. et al. (2002) *Nature, 418,* 952-955. [16] Ransford G.A. (1982) *PEPI, 29,* 209-217. [17] C. G. Chase, P. J. Patchett, *EPSL, 91,* 66-72 (1988). [18] Galer S.J., Goldstein S.L. (1990) *GCA, 55,* 227-239 (1990). [19] T. Kato, et al. (1988) *EPSL, 89*, 123-145.