Mesosiderites offer a unique view into early solar system history because (1) they consist of mixtures of components thought to represent the crust and mantle (differentiated silicates) and core (Fe-Ni metal) of planetesimals; (2) they are early objects formed within 0.2 AE of the formation of the solar system [1-4]; and (3) mesosiderite silicates exhibit some of the most extreme trace element fractionations observed in differentiated materials [2, 5-7]. This work represents part of a study in which we address fundamental issues of mesosiderite petrogenesis and chronology using the coupled short-lived \(^{146}\text{Sm}-^{142}\text{Nd}\) (\(T=0.149\) AE) and long-lived \(^{147}\text{Sm}-^{143}\text{Nd}\) (\(T=153\) AE) isotope systems, as well as ion probe trace element data and other petrochemical techniques. We present data from two Vaca Muerta silicate clasts (pebbles 5 and 12, generously provided by A.E. Rubin and J.T. Wasson) and from the Mt. Padbury basaltic clast.

Vaca Muerta (VM) was chosen because it is a group 1A (least metamorphosed) mesosiderite with numerous diverse samples available. Pebble 5 (VM-5) consists primarily of cm-scale bands of highly recrystallized plagioclase (Pl, \(-40\%\)) alternating with coarser, partially recrystallized pigeonite (Px, \(-60\%\)). It has been interpreted as an impact melt that has undergone extensive subsolidus recrystallization. Pebble 12 (VM-12) is a coarse-grained (0.5-2 mm) pigeonite-plagioclase cumulate with minimal evidence of subsolidus recrystallization. Mt. Padbury contains subequal amounts of Pl and Px (pigeonite+minor clinopyroxene) in a medium-coarse igneous texture, and minimal evidence of recrystallization. Each of these mesosiderite clasts contains small amounts (\(<1\%) of phosphates, although the fractionation that occurred in the meteorite is unknown. Leaching experiments show that phosphates, in spite of their low abundances, generally carry minor evidence for subsolidus recrystallization. Such evidence for mixing of the Fe-Ni metal with silicate melt and the presence of sub-solidus recrystallization is most clearly demonstrated by the phosphates, which are generally considered to be a signature of this process.

Concentrations of Sm and Nd and isotope ratios of \(^{143}\text{Sm}/^{144}\text{Nd}\) and \(^{142}\text{Nd}/^{144}\text{Nd}\) were measured on PI, Px and total rock (TR) fractions from each of the mesosiderite silicate clasts. In all cases, PI and Px were leached for 10 minutes in warm 2.5N HCl to remove phosphate and iron staining. For increased sensitivity, spiked Sm and Nd samples were measured as oxide ions, and the Nd data were corrected for isotope fractionation using \(^{146}\text{Nd}/^{144}\text{Nd}\). The VM-5 mineral separates and total rock define a relatively precise linear array corresponding to an age of 4.42\pm0.02 AE with an initial (at 4.42 AE) \(\epsilon_{143}\) of 3.4\pm0.4 (Fig. 1). Measured \(^{142}\text{Nd}/^{144}\text{Nd}\) (\(\epsilon_{142}\)) correlate with \(^{147}\text{Sm}/^{144}\text{Nd}\) (Fig. 1a), with all points falling along a linear regression which corresponds to an initial \(^{146}\text{Sm}/^{144}\text{Nd}\) of 0.0042\pm0.0017, and an initial \(\epsilon_{142}\) of -1.6\pm0.7. As reported previously [2], VM-12 has very low LREE abundances and a high TR Sm/Nd ratio, with extreme Sm/Nd fractionation between PI and Px. The Px, PI and TR points define a linear array corresponding to an age of 4.47\pm0.15 AE and initial \(\epsilon_{143}\) of 15\pm11 (Fig. 2). The small deviations from the linear regression (\(\epsilon\), deviations from the curve in \(\epsilon\) units, Fig. 2 inset) indicate that the system has been somewhat disturbed. VM-12 \(\epsilon_{142}\) data show a large spread of 6.2 \(\epsilon\) (Fig. 2a) due to the extreme Sm/Nd fractionation between PI and Px; a linear regression yields an initial \(^{146}\text{Sm}/^{144}\text{Sm}\) ratio of 0.0057\pm0.0015, and an initial \(\epsilon_{142}\) of -0.1\pm2.0. For Mt. Padbury, isotopic ratios were measured on a leachate of a Px separate, thought to represent phosphate, in addition to two PI and two Px separates. The well-defined linear data array (Fig. 3) yields an age of 4.51\pm0.04 AE and an initial \(\epsilon_{143}\) of -0.2\pm0.9. The \(\epsilon_{142}\) data (Fig. 3a) yield an initial \(^{146}\text{Sm}/^{144}\text{Sm}\) of 0.0056\pm0.0007 and an initial \(\epsilon_{142}\) of -2.0\pm0.3.

The combined \(^{147}\text{Sm}/^{143}\text{Sm}\) and \(^{146}\text{Sm}/^{142}\text{Sm}\) data clearly show that mesosiderites are early objects that were last isotopically homogenized prior to 4.4 AE. \(^{146}\text{Sm}\) was alive at the last time of isotopic homogenization of all mesosiderites for which \(^{142}\text{Nd}\) has been measured, based on large and unambiguous variations in \(^{142}\text{Nd}\) abundances. Because the phosphates in these mesosiderites appear to be equilibrated with the major phases with respect to their REE abundances, we suggest that the time of last isotopic homogenization corresponds to the time at which phosphate was introduced to the silicates by oxidation of P during mixing with the metal. If "goodness of fit" criteria are applied to the linear regressions in order to evaluate the significance of the calculated \(^{147}\text{Sm}-^{143}\text{Nd}\) ages, then the regressions through the Vaca Muerta pebble 5 and Mt. Padbury data can be considered isochrons, while the correlation formed by the pebble 12 data is not interpretable as a precise age. We note, however, that Prinzhofer et al. [9] have demonstrated that even apparently well-behaved linear arrays may not have precise age.
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147Sm/144Nd ratios at the time of solar system formation (taken to be 4.57 AE) range from 0.008 (Mt. Padbury) to 0.011 (Vaca Muerta pebbles). These numbers suggest that at least 0.05% of 142Nd in the solar system was formed from the decay of 146Sm.

Even if the Sm-Nd ages are slightly disturbed, total rock 143Nd/144Nd ratios of Vaca Muerta pebbles 5 and 12 must still have been elevated relative to chondrites at the time of formation, assuming that each clast remained a closed system with respect to REE subsequent to this time. Using the 147Sm/144Nd ratios at the time of isotopic equilibration, Sm/Nd ratios of the source materials must have been even higher than those measured in the samples. This can be explained with a three-stage model involving (1) creation of a source rich in orthopyroxene, with subordinate plagioclase and possibly olivine; (2) extraction of partial melts early in its history to increase the Opx/P1 and Sm/Nd of the source, allowing extensive growth of 143Nd; (3) partial melting of the source to produce a liquid that crystallized P1+Px in roughly equal proportions [10], thus creating cumulates with the more moderate Sm/Nd ratios measured today. The initial ε143 value of pebble 12 requires a source with Sm/Nd=2.1, a factor of 2.6 higher than the (already high) Sm/Nd ratio measured. For pebble 5, a source with Sm/Nd=0.63 is necessary to produce the elevated initial ε143, while Mt. Padbury was extracted from a source with a chondritic Sm/Nd ratio. The variations in initial ε143 clearly show that each of the clasts was derived from a distinct igneous source. From a broader planetological point of view, we note that the parent body to mesosiderite silicates must have been a highly differentiated planetary object with a complex history. Processes apparently operated on very short timescales to produce extreme chemical fractionations generally not observed in terrestrial rocks. The diversity of differentiation products and of Sm/Nd fractionations is comparable to that observed on the moon[11-13].