Sm-Nd SYSTEMATICS OF MESOSIDERITES

Brian W. Stewart, Q. Charles Cheng, D. A. Papanastassiou and G. J. Wasserburg, The Lunatic Asylum, Division of Geological and Planetary Sciences, Caltech, Pasadena, CA 91125

The chronology and petrogenesis of mesosiderite parent bodies and the relationship of mesosiderite silicate clasts to eucrites and howardites remain important problems in the study of planetary formation and differentiation in the early solar system. We present data from a highly unusual gabbroic pebble from the Vaca Muerta mesosiderite and from a basaltic clast from Mt. Padbury. This work represents part of a continuing effort [1-4] to determine the chronology and petrogenesis of mesosiderites using long-lived (^{147}Sm-^{143}Nd; $\tau_{1/2}$=106 AE) and short-lived (^{146}Sm-^{142}Nd; $\tau_{1/2}$=0.103 AE) isotope systems and petrologic tools. The Vaca Muerta clast (pebble 12) was generously provided by A. E. Rubin and J. T. Wasson [5-7]. It is a gabbroic cumulate composed of subequal amounts of pigeonite (Px) and plagioclase (Pl), with accessory phosphate, opaque phases and tridymite. The Pl occurs in unzoned, 0.2-1 mm grains often showing evidence of recrystallization (granular texture, 120° grain boundaries); original cumulate textures are rarely preserved. Most Pl grains contain phosphate inclusions in their cores, and rare Px inclusions; secondary alteration is minimal. The Px grains (0.5-2 mm) are subhedral to irregular and display extensive exsolution. Small (0.1-0.2 mm), rounded inclusions of Pl are quite common, and the Px shows greater fracturing and Fe-staining than the Pl. Opaque phases are finely disseminated along pyroxene grain boundaries. Except for 2-3 mm patches affected by terrestrial weathering, Vaca Muerta pebble 12 is relatively fresh and unaltered. Pl and Px separates (60-200 µm) were leached for 10 minutes in warm 2.5N HCl to remove Fe-stains and phosphate prior to dissolution, while the whole rock (WR) powder (<40 µm) was not leached. Pebble 12 has both very low REE concentrations and extreme Sm/Nd fractionation, with $(Sm/Nd)_{WR} = 2.5x(Sm/Nd)_{CHUR}$ (Table 1). Trace element concentrations from a leached WR aliquot (not shown) indicate that the phosphate contains ~50% of the Nd and 35% of the Sm. Low concentrations resulted in only 2-4 ng of Nd available for analysis; uncertainties in the $^{143}Nd/^{144}Nd$ and $^{142}Nd/^{144}Nd$ of 1.6 εu (2σ) or better were obtained by running the Nd as NdO^+ with an ionization efficiency of ~10% on the Lunatic I spectrometer. Because of the presence of ^{142}Nd isotopic effects, ratios were corrected for isotope fractionation using $^{146}Nd/^{144}Nd$. Sm (0.6 to 3 ng) was run as SmO^+.

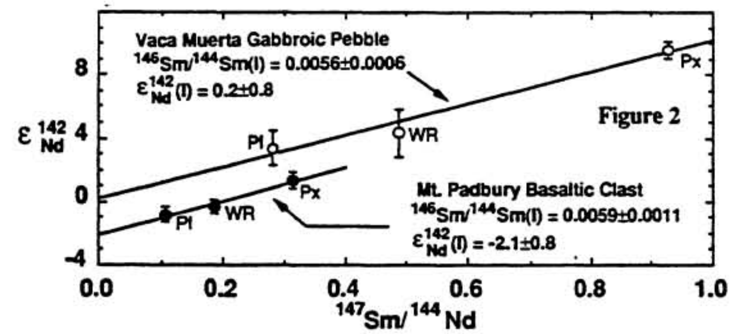
The two Vaca Muerta mineral separates and WR define an internal ^{147}Sm-^{143}Nd isochron age of 4.47±0.07 AE (Fig. 1), with a spread in $^{143}Nd/^{144}Nd$ of 374 εu and an initial ε_{143} = 14.1±4.8. It is clear that the points do not lie precisely on the isochron (ξ, deviations in $^{143}Nd/^{144}Nd$, Fig. 1 insert), which is direct evidence that the system is disturbed. However, this age is indistinguishable from the Sm-Nd internal isochron ages of the Morristown mesosiderite (4.47±0.02 AE) and Ibitira eucrite (4.46±0.03 AE)[3]. Excess ^{142}Nd is plotted against $^{147}Sm/^{144}Nd$ in Figure 2. The extreme Sm/Nd ratio of this sample provides the clearest evidence to date for the existence of ^{146}Sm and its *in situ* decay, with the ε_{142} of Px reaching 9.6±0.5 εu (Table 1, Fig. 2). Regression of the $^{142}Nd/^{144}Nd$ data gives an initial $^{146}Sm/^{144}Sm$ = 0.0056±0.0006 (compared to 0.0075±0.0011 and 0.009±0.001 for Morristown and Ibitira, respectively [3]) and $\varepsilon_{142}(I)$ = 0.2±0.8. A value for $^{87}Sr/^{86}Sr$ of 0.69902±0.00003 was measured on the Pl separate, giving $^{87}Sr/^{86}Sr$(4.47 AE) = 0.69901±0.00003 with $^{87}Rb/^{86}Sr$ = 0.0002.

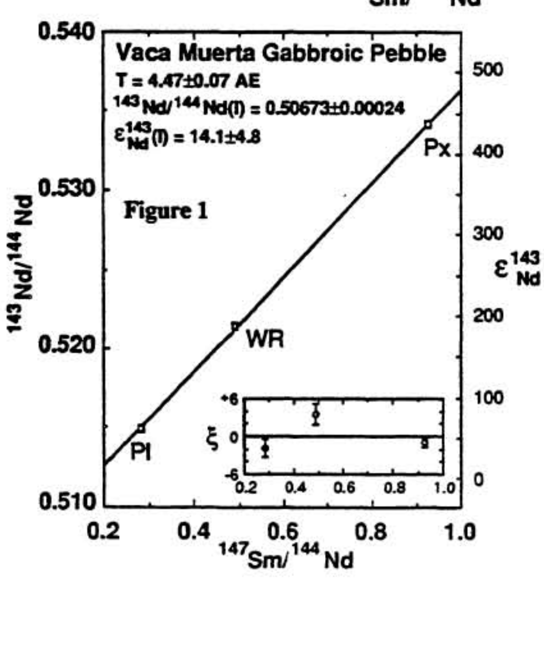
We also present data (Table 1) on a basaltic clast from Mt. Padbury composed of Pl (An_{95}), Opx (inverted pigeonite, En_{45-50}), Cpx (ferrosilite), tridymite, troilite, Cr-spinel and ilmenite. Phosphates are found as veins in plagioclase. The Sm and Nd concentrations in this basalt are much higher than in the Vaca Muerta pebble. Mt. Padbury yields a ^{147}Sm-^{143}Nd isochron age of 4.47±0.03 AE (Fig. 3), which is indistinguishable from the Sm-Nd ages of other mesosiderites, and an initial ε_{143} = -0.2±0.6. The ^{146}Sm-^{142}Nd system (Fig. 2) yields $^{146}Sm/^{144}Sm$ = 0.0059±0.0011 and initial ε_{142} = -2.1±0.8.

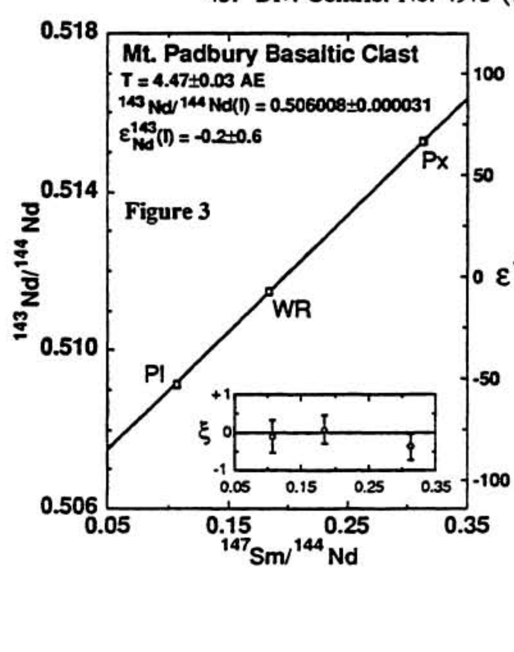
We conclude the following from this study: a) The ^{147}Sm-^{143}Nd internal isochrons from Vaca Muerta and Mt. Padbury give relatively early formation ages consistent with other mesosiderite Sm-Nd ages. b) Both mesosiderites studied provide clear evidence for the extinct nuclide ^{146}Sm, with the Vaca Muerta pebble yielding the highest unequivocal $^{142}Nd/^{144}Nd$ excess yet measured. c) The age and ^{146}Sm-^{142}Nd systematics of Vaca Muerta appear to be substantially preserved despite evidence for disturbed ^{147}Sm-^{143}Nd systematics. If the disturbance was as recent as the ca. 3.8 AE ^{39}Ar-^{40}Ar ages for mesosiderites [8], it must have only slightly re-equilibrated the Sm-Nd system [Prinzhofer *et al.*, in preparation]. d) The ^{147}Sm-^{143}Nd internal isochron ages are remarkably clustered at 4.47 AE despite the observation of slow mesosiderite cooling rates [9-12]. It is possible that the Sm-Nd systematics became quenched over a short time interval at higher temperatures than those measured by cooling rate indicators. e) The high model ages (T_{CHUR}, Table 1) and high initial ε_{143} of Vaca Muerta suggest that its parent material prior to the time of isotopic homogenization had a $^{147}Sm/^{144}Nd \geq 0.8$, which is higher than $(^{147}Sm/^{144}Nd)_{WR}$ measured in this study; however, the $\varepsilon_{142}(I)$ value of Vaca Muerta is not sufficiently evolved in comparison to its $\varepsilon_{143}(I)$ value. This discrepancy requires further attention, including consideration of the mechanism of Sm-Nd system disturbance and the possibility of significant deficits in initial ε_{142} in the precursor materials. f) The primitive $^{87}Sr/^{86}Sr$ ratio indicates that the Vaca Muerta parent material was extremely depleted in Rb within 10^6-10^7 yr of the beginning of the solar system. g) The low concentrations of Sm and Nd and high Sm/Nd ratio in the Vaca Muerta gabbro necessitate multiple-stage fractionation events, as suggested in recent reports [6,7,13].

We envision the following sequence for the Vaca Muerta pebble: (1) Fractionation of the source material to produce extreme depletion in the LREE and alkalis within 10^6-10^7 yr of the formation of the solar system (4.55-4.6 AE); (2) mixing of the silicate source with metal at 4.47 AE; (3) heating associated with the introduction of metal, resulting in recrystallization of the silicates and isotopic homogenization; (4) late collisional breakup and metamorphism at 3.4-3.8 AE which reset ^{40}K-^{40}Ar [8] but affected Sm-Nd to a minor extent. During stage (3), phosphate derived from the metal and REE from other clasts may have been introduced to moderate the Sm/Nd to its present value. We conclude that mesosiderites are useful tools in addressing planetary evolution in the early solar system, despite their complex histories.

Table 1.	Weight (mg)	Sm (ppb)	Nd (ppb)	$^{147}Sm/^{144}Nd$	$f^{Sm/Nd}$	ε(143)	ε(142)	T_{CHUR} (AE)	$^{87}Sr/^{86}Sr(I)$
Vaca Muerta-gabbroic Pebble 12									
Plag. (leached)	99	9.24	19.86	0.2813	0.430	61.0 ± 1.5	3.3±1.1	5.55	0.69901 ± 3
Whole Rock	95	38.6	47.9	0.4887	1.485	186.6 ± 1.6	4.3±1.5	4.92	
Pyrox. (leached)	103	44.3	29.12	0.9261	3.708	435.5 ± 0.7	9.6±0.5	4.60	
Mt Padbury-basalt clast									
Plag. (leached)	22	170.4	970.	0.1062	-0.460	-52.7 ± 0.4	-0.8±0.5	4.49	
Whole Rock	20	1185.	6574.	0.1845	-0.0622	-7.1 ± 0.4	-0.3±0.4	4.47	
Pyrox. (leached)	21	2005.	2291.	0.3132	0.592	66.6 ± 0.3	1.3±0.5	4.41	







Refs. [1] Jacobsen & Wasserburg (1984) EPSL 67, 137; [2] Prinzhofer et al. (1989) LPSC XX, 872; [3] Prinzhofer et al. (1989) Ap. J. 344, L81; [4] Prinzhofer et al. (1990) LPSC XXI, 981; [5] Wasson & Rubin (1985) Nature 318, 168; [6] Rubin & Jerde (1987) EPSL 84, 1; [7] Rubin & Jerde (1988) EPSL 87, 485; [8] Bogard et al. (1990) GCA 54, 2549 [9] Begemann et al. (1976) GCA 40, 353; [10] Crozaz & Tasker (1981) GCA 45, 2037; [11] Narayan & Goldstein (1985) GCA 49, 397; [12] Saikumar & Goldstein (1988) GCA 52, 715; [13] Mittlefehldt (1990) GCA 54, 1165. Supported by NASA, NAG9-43. Div. Contrib. No. 4973 (728)