Search for evidence of ^{26}Al in meteorites that are planetary differentiates

Mark T. Bernius, I.D. Hutcheon and G. J. Wasserburg
The Lunatic Asylum, Charles Arms Laboratory of Geological Sciences, California Institute of Technology, Pasadena CA 91125

In 1955 H.C. Urey first postulated the potential role of ^{26}Al as a heat source for melting early planets which may be the source for differentiated basaltic achondrites (1). After several decades, the presence of excess ^{26}Mg ($^{26}Mg^*$) correlated with Al was demonstrated in anorthite from inclusion WA of Allende (2) with an abundance of $^{26}Al/^{27}Al \sim 5 \times 10^{-5}$. This observation has been extended to many other CV meteorites (3). Evidence for $^{26}Mg^*$ is restricted to carbonaceous chondrites and two unequilibrated ordinary chondrites, but some evidence for $^{26}Mg^*$ in planetary differentiates found very early in the solar system has been found (4,5). In particular, a recent study has reported positive evidence for ^{26}Al in a basaltic clast in the ordinary chondrite Semarkona (5) with an initial abundance of $^{26}Al/^{27}Al \sim 8 \times 10^{-6}$ (corresponding to a time interval of 1.9 Myr). This level of ^{26}Al is sufficient to produce incipient melting in well-insulated bodies of chondritic composition. It is further inferred from $^{107}Pd^*$ studies (6) that many iron meteorites formed within 10 Myrs after the formation of the solar system. If ^{26}Al was the heat source for melting small, early planetary bodies, then some evidence for its existence should be preserved in the differentiated meteorites, if their parent bodies cooled on a timescale comparable to 1 - 3 Myr. To date, no clear evidence of ^{26}Al has been found in planetary objects such as eucrites to support this view, but the question regarding the heat source for planetary differentiation remains.

Current efforts entail a more extensive study of meteoritic basaltic clasts reflecting planetary differentiation. Analyses of plagioclase and pyroxene were made in Morristown, Mt. Padbury, Vaca Muerta, Barea, Estherville, Hainholz, Patwar, Emery, Bondoc, Pasamonte, Ibitira, Jonzac, Juvinas, Moama and Acapulco. The isotopic measurements were performed with the Panurge ion probe using a mass resolving power of 3500. Isotope fractionation factors and variations in $\delta^{26}Mg$ are calculated from the deviations of the measured $^{25}Mg/^{24}Mg$ and $^{26}Mg/^{24}Mg$ ratios, respectively, relative to the values in mineralogically similar standards. Results are presented in Table1. Mg in pyroxene in all samples showed normal isotopic composition and revealed no evidence for mass fractionation within 2σ limits of 3 ‰. Analyses of plagioclase failed to reveal any evidence of $^{26}Mg^*$, which is consistent with the results of Schramm et al. (7) for Juvinas and Pasamonte. We calculate the maximum value of $^{26}Al/^{27}Al$ using the 2σ errors from $\delta^{26}Mg$ and the measured Al/Mg. These data represent upper limits to the initial ^{26}Al abundance at the time of crystallization. Assuming an initial state of $^{26}Al/^{27}Al = 5 \times 10^{-5}$ as observed in many CAIs, this implies a minimum formation time interval of greater than 5 Myr between the CAIs and all samples analyzed. Therefore, we are left with no direct evidence for ^{26}Al as a heat source in these objects. The samples studied formed late or underwent isotopic re-equilibration due to slow cooling or metamorphism. The absence of ^{26}Al is consistent with the relatively young Sm-Nd ages for most mesosiderites. Recent studies of the Sm-Nd isotopic system in two mesosiderites give apparent crystallization ages of 4.47 Ae (8,9). In addition, ^{40}Ar - ^{39}Ar studies of mesosiderites provide strong evidence for several metamorphic thermal events causing partial isotopic re-equilibration, approximately 3.9 AE ago (10). The extent to which the metamorphism has resulted in Mg isotopic re-equilibration is not known.

^{207}Pb - ^{206}Pb dating of the eucrites suggests a formation time of 4.555 AE (11), but Sm-Nd chronometry indicates a later formation (equilibration) time of 4.47 AE ago (9). This clearly indicates metamorphism and recrystallization ~ 100 Myr after formation, and would explain the absence of $^{26}Mg^*$.

TABLE 1

Meteorite	Type	% An	$\delta^{26}Mg$ (‰)	$^{27}Al/^{24}Mg$	$(^{26}Al/^{27}Al)_{max}$ (a) (x 10^{+6})
Morristown	MES	90	-2.5 +/- 4.0	595	0.35
Vaca Muerta	MES	94	-3.9 +/- 7.6	1206	0.42
Mt. Padbury	MES	92	-1.3 +/- 5.1	615	0.86
Barea	MES	88	0.7 +/- 2.9	503	1.00
Estherville	MES	86	2.1 +/- 5.7	727	1.50
Hainholz	MES	93	1.3 +/- 3.6	524	1.31
Patwar	MES	93	-2.1 +/- 4.3	818	0.37
Emery	MES	86	-2.1 +/- 11.4	584	2.22
Bondoc	MES	90	-1.1 +/- 5.0	601	0.90
Pasamonte	EUC	87	0.8 +/- 3.6	516	1.19
Ibitira	EUC	96	-2.9 +/- 5.7	862	0.45
Jonzac	EUC	84	-1.4 +/- 2.0	528	0.16
Juvinas	EUC	92	-4.1 +/- 4.3	205	0.12
Moama	EUC	96	-1.6 +/- 4.3	957	0.39
Acapulco	A-CHON	20	-2.4 +/- 8.7	5400	0.16

(a) Maximum value calculated using the 2σ uncertainty of $\delta^{26}Mg$.

In summary, none of the objects examined shows evidence for ^{26}Al at the time of final crystallization of the eucrites and mesosiderites. Late-stage metamorphism remains an explanation for re-equilibration, but by a heat source other than ^{26}Al unless the parent bodies are very well insulated. There is no positive evidence for ^{26}Al contributing to planetary differentiation of the eucrites, and we conclude that the heat source for these meteorites associated with planetary differentiation processes was most likely due to collision and not radioactive decay. The detailed chronological relationship between the various classes of meteorites is not yet firmly established, and the basic problem Urey posed in 1955 is not yet resolved. It is of course possible that earlier formed objects [including some planetary differentiates (5) and possibly comets] had a strong ^{26}Al heat source.

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