

^{84}Sr ANOMALIES IN CARBONACEOUS CHONDRITES Frédéric Moynier¹, James M.D. Day^{2,3}, Audrey Bouvier⁴, and Richard J. Walker² and Frank A. Podosek¹, ¹Dept. Earth Planet. Sci., Washington University, St Louis, MO 63130 (moynier@levee.wustl.edu); ²Dept. Geology, University of Maryland, College Park, MD 20742; ³Geosci. Res. Div., Scripps Institution of Oceanography, La Jolla, CA 92093; ⁴SESE, Arizona State University, Tempe, AZ 85287

Introduction: Some primitive meteorites contain small quantities of several mineral phases that have been plausibly identified as relatively pristine interstellar dust, largely unmodified by processing in the solar nebula and in meteorite parent bodies [1-5]. Of these presolar phases, silicon carbides (SiC) are perhaps the best known. Typically, the isotopic compositions of major, minor, and trace elements in presolar phases are radically different from solar “normal” compositions; indeed, this is the primary criterion by which they are recognized as presolar. The character, survival, and isotopic compositions of such presolar grains provide important constraints for studies of stellar evolution and nucleosynthesis, processing in the interstellar medium (ISM), and the formation of the Solar System [3].

Strontium has four stable isotopes ^{84}Sr (0.56 %), ^{86}Sr (9.86%), ^{87}Sr (7.00%) and ^{88}Sr (82.58%). ^{86}Sr , ^{87}Sr , ^{88}Sr are all made by the same nucleosynthetic process, the slow neutron capture process (*s*-process), whereas ^{84}Sr is a proton-rich nuclide made by the *p*-process. *p*-, *s*- and *r*-processes occur in different stellar environments (*s*-process in Asymptotic Giant Branch stars; *p*- and *r*-processes in Supernovae) and then are apparently mixed, ultimately to make the isotopic composition of a bulk chondrite; what we will define as the “normal” isotopic composition. Since presolar grains were formed in different stellar environments rather than mixing in the solar nebula, an expectation is that they should retain Sr isotopic compositions anomalous from the solar “normal” composition.

To that end, Podosek et al. [6] measured the Sr isotopic compositions of separated SiC fractions from the Murchison (CM) chondrite and found that, as for other heavy elements, their Sr isotopic compositions are radically different from “normal”, with large possible enrichments in *s*-process isotopes, probably because of the contribution of Asymptotic Giant Branch stars. On the other hand, the relative abundances of *s*-process ^{86}Sr , ^{87}Sr , and ^{88}Sr in Murchison SiC are very similar to early Solar System materials (CAIs from the Allende chondrite [7]) but in view of the different *s*-process superpositions and other contributions to all three of these isotopes, the close agreement is puzzling and seems coincidental. To correct for the instrumental fractionation, Podosek et al. (7) spiked their Sr fractions with ^{84}Sr and so considered that ^{84}Sr was “normal” in CAIs. If there are any anomalous nucleosynthetic components for ^{84}Sr in CAIs, it would affect all the other isotopes and so the unexpected agreement between the Sr isotopic composition of CAIs and SiC

would be lost. These potential nucleosynthetic effects may also have chronological implications. Here, we use high precision techniques to examine ^{84}Sr in terrestrial samples, CAIs, and bulk meteorites. Early studies have demonstrated ^{84}Sr anomalies in FUN inclusions from Allende of as much as $\epsilon^{84}\text{Sr} = -42$ [8] ($\epsilon =$ part per 10000 deviation from the terrestrial value). Following these tantalising results, we present high-precision, unspiked static measurements of Sr by thermal ionization mass spectrometry (TIMS) using the University of Maryland (UMD) Triton, as part of our on-going study to characterise Sr isotopic variability in early Solar System materials.

Samples and Analytical methods: A variety of geological reference materials from different magmatic settings on Earth were analyzed (BHVO-2, BCR-2, G2, PCC1, BIR-1); along with 3 eucrites meteorites (Stannern, Juvinas and Pasamonte); 3 carbonaceous chondrites: Ornans [CO3], Allende [CV3] and Murchison [CM2]; 3 ordinary chondrites: Alfianello [L6], Forest Vale [H4], and Bath [L6]; NWA 2976 (basaltic achondrite), and 2 CAIs from Allende [CV3]. NWA 2976 is an ungrouped basaltic achondrite, paired with NWA 011 and composed primarily of pyroxene, plagioclase, and chromite [9].

For every bulk sample, 200-300 mg of homogenous powder was dissolved in a HF/HNO₃ mixture. Chondrites, CAI and NWA 2976 samples were dissolved under pressure in Parr bombs whereas the terrestrial samples as well as the eucrites were dissolved in closed Teflon beakers at 130°C for several days. After evaporation of the HF/HNO₃, the samples were re-dissolved in aqua regia at 130°C for several days in order to ensure the total dissolution of fluorides.

Strontium purification from the matrix is achieved using micro-columns filled with 300 μl of Eichrom Sr spec resin. Samples are loaded in 4N HNO₃ and the matrix is washed with 4 mL of 4HNO₃, with Sr collection in warm water. This procedure is performed three times to ensure high-purity Sr fractions. High precision Sr isotope measurements are accomplished on the UMD Triton TIMS in positive ion mode. ~500ng of Sr of both unknown and standard are loaded onto single out-gassed Re filaments in 1M HCl with a Ta₂O₅ activator slurry. Intense and stable signals are achieved with ~500ng Sr and measurement involves acquisition in static mode, with steady 5V ^{88}Sr signals throughout the ~3.5 hr analysis.

Isotope ratios are expressed in ϵ units after internal normalization to a $^{88}\text{Sr}/^{86}\text{Sr}$ ratio of 8.375209. The

long-term external precision from the terrestrial standard (NBS SRM-987) for the $^{84}\text{Sr}/^{86}\text{Sr}$ ratio is 20 ppm (2σ ; 0.0564664 ± 6 ; $^{87}\text{Sr}/^{86}\text{Sr} = 0.7102526 \pm 11$).

Results and Discussion: As shown in Fig. 1, the weighted average of the different groups of samples analyzed in this study show small but resolvable isotopic variations. Ordinary chondrites and eucrites have $\epsilon^{84}\text{Sr}$ similar to terrestrial samples, within uncertainties. Carbonaceous chondrites are enriched in ^{84}Sr compared to terrestrial samples with $\epsilon^{84}\text{Sr} = +0.54 \pm 0.25$.

NWA 2976 is similar to carbonaceous chondrites within error ($\epsilon^{84}\text{Sr} = +0.37 \pm 0.20$). CAIs are even richer in ^{84}Sr with $\epsilon^{84}\text{Sr} = +1.21 \pm 0.27$. The results in chondrites and eucrites agree with previous studies within error [10], however our marginally higher precision and more extensive sampling has revealed isotopic variations and excess p -process Sr (or deficit in the s -process Sr) in CAIs, an ungrouped basaltic achondrite, and carbonaceous chondrites relative to terrestrial.

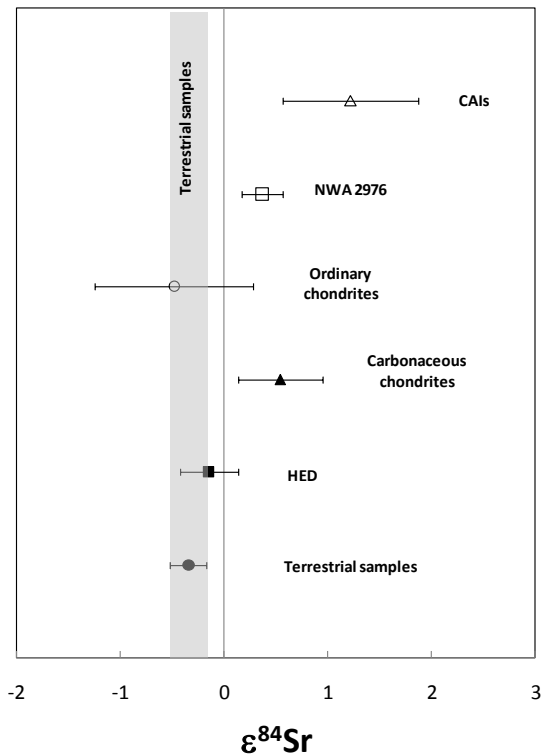


Figure 1: $^{84}\text{Sr}/^{86}\text{Sr}$ ratios (weighted averages and respective error bars at 2SE) for different groups of samples analyzed here. The isotope ratios are expressed in ϵ units after internal normalization to the $^{88}\text{Sr}/^{86}\text{Sr}$ ratio. The standard reference material is NBS SRM-987.

An important implication of our new results is that, at the scale of chondrite parent bodies, the $^{84}\text{Sr}/^{86}\text{Sr}$

ratio was heterogeneously distributed in the early Solar System. Additionally, homogenization of $^{84}\text{Sr}/^{86}\text{Sr}$ appears to have occurred in large differentiated parent bodies (e.g., Earth, HED parent body)

An intriguing result is the identification of similar positive $\epsilon^{84}\text{Sr}$ anomalies in the achondrite NWA 2976 to carbonaceous chondrites. This result is consistent with isotopic anomalies of O, Ti and Cr in NWA 2976 that are of a similar magnitude to those observed for carbonaceous chondrites [11].

Carbonaceous chondrites show ~ 200 ppm positive anomalies in the p -process ^{94}Mo and ~ 100 ppm negative anomalies in the p -process nuclides ^{144}Sm and ^{146}Sm compared to terrestrial samples and ordinary chondrites [12-13]. Interestingly, the present positive ^{84}Sr anomalies are positively correlated with the low mass p -process nuclide ^{94}Mo measured in carbonaceous chondrites. This suggests a decoupling between p -process for low masses (Sr, Mo) and high masses (Sm) as observed for r -process nuclides [14].

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