ORIGINS OF NUCLEOSYNTHETIC ISOTOPIC HETEROGENEITY IN THE SOLAR SYSTEM K.R. Bermingham[1,2], B. Meyer[3], K. Mezger[1,4], [1]Institut für Mineralogie, Westfälische Wilhelms-Universität, Corrensstraße 24, 48149 Münster, Germany; [2]Isotope Geochemistry Laboratory, Department of Geology, University of Maryland, College Park, MD-20742 USA; [3]Department of Physics and Astronomy, Clemson University, Clemson, SC, USA. [4]Institut für Geologie, Universität Bern, Baltzerstrasse 1 + 3, 3012 Bern, Switzerland. Email: kberming@umd.edu.

Introduction: Several different nucleosynthetic processes (e.g., *s*-, *r*-, *p*-processes; [1]) contributed material to the solar system. Further, isotopically distinct materials may have been injected into the solar nebula at different times [2]. However, the relative contributions of each process and how their products were mixed in the solar nebular are still poorly constrained. This information is key to understanding early solar system history because these data can be used to determine the number and type of supernova contributors to the solar system. Understanding the extent of isotopic variability in the solar nebula is also needed in order to apply chronometers based on short- and long-lived radioisotopes.

A compilation of whole rock isotope data for different, multi-isotope elements shows that small (≤1 ε, where *ε*-unit = 0.01% deviation from terrestrial isotope composition) isotope variations have been identified in ^{58,64}Ni [3-5], ^{84}Sr [6], ^{96}Zr [7], and ^{135,137}Ba [8-12]. By contrast, no nucleosynthetic isotope anomalies have been found in Te [13] or Os [14]. Some elements are characterized by large resolved isotope anomalies (1-5 ε; e.g., ^{46,50}Ti [15,16], ^{54}Cr [17-18], ^{92,94,95,97,100}Mo [19], ^{100}Ru [20], ^{142}Nd, ^{144}Sm [9], and ^{180,184}W [21-22]).

Recent discussions addressing the absence and variability in magnitude of nucleosynthetic anomalies in bulk samples focus on explaining how processes within the disk can affect the mixing of highly isotopically anomalous presolar grains or 'unmixing' of previously homogeneously distributed components by thermal processing [3,4,16,17,23]. An additional way to investigate this question is to determine if processes prior to disk formation may have some influence on presolar grain homogenization the asteroid or planetary scales in the disk.

Here, the relationship between the proportion of nucleosynthetic processes which contributed to an element, and the degree of heterogeneity exhibited by its isotopes on the bulk rock meteorite scale, is investigated using a time-dependent multi-reservoir mixing code. *Prima facie*, a correlation between the nucleosynthetic origins of an element and the degree of its isotopic heterogeneity in the solar system seems unlikely. The solar system, however, comprises multiple generations of dust and gas whose compositions and relative proportions were defined during nucleosynthesis. Thus, it is feasible that a relationship exists between the assortment of nucleosynthetic processes which contributed to an element, and the degree of isotopic heterogeneity in the disk.

Results and Discussion:

A compilation of isotope data from whole rock meteorite samples is contrasted with the predicted contributions of the *s*-process to the solar elemental abundances for these elements [from 24]. The predicted *s*- and *r*-process contributions to heavy elements characterized by ≤1 ε to no resolvable isotope anomalies, are dominated (>80 %) by either the *s*-process (Sr, Zr and Ba), or the *r*-process (Te and Os). Conversely, lighter elements that formed during supernova events and had multiple nucleosynthetic processes contribute to their overall abundance display large isotope variations on the bulk scale (≤5 ε; ^{46,50}Ti and ^{54}Cr). The heavy elements that had substantive contributions from both the *r*- and *s*-processes (^{100}Ru, ^{92,94,95,97,100}Mo; 30 - 56 %) or the *p*-process (^{142}Nd, ^{144}Sm and ^{180}W) also display larger isotopic variations on the bulk sample scale (≤6 ε).

On the basis of published isotope data for the different elements, there appears to be a correlation between the predominance of a single nucleosynthetic process, which contributes to the abundance of an element, and the degree of isotope variability in the Solar system. Specifically, elements whose isotopes are mainly synthesized during a single nucleosynthetic event possess small to undetectable isotope anomalies on the bulk sample scale (e.g., Ba, *s*-process). Whereas, elements comprised of isotopes produced in significantly different (40 - 50 %) abundances, by various nucleosynthetic processes, have isotopes that are heterogeneously distributed on the whole rock sample scale (e.g., Mo *s*- and *r*-process).

The observation of nucleosynthetic isotope variations among different asteroidal and planetary bodies implies mixing of at least two end member components with different nucleosynthetic origins. The detection of such mixtures depends on the difference in the isotope abundances of the end members, and the relative differences in the amount of these components that contribute to the mixtures.

A possible reason why some isotopic systems that had substantive contributions from multiple nucleosynthetic processes exhibit larger anomalies on the bulk sample scale than those isotopic systems with contribu-

tions from predominately one nucleosynthetic source, may be because the starting mixture for the former, which comprises multiple presolar components, is significantly more compositionally variable and thus easier to detect.

To test this model, a time-dependent multi-reservoir mixing code was used. For the initial tests using Mo and Ba, three reservoirs were set up, an *s*-process reservoir, an *r*-process reservoir, and a "processed" reservoir. The "processed" reservoir contains all the mass that has already been mixed together prior to solar system formation. Relative masses for the three reservoirs were set up and then apportioned the *s*-process and *r*-process isotopic abundances of Mo and Ba, as decomposed in [25], into their respective reservoirs. Subsequently, the abundances in the processed reservoir were set such that the sum over all reservoirs gave the final solar abundances. The *r*-process and *s*-process reservoirs were set to transfer mass via solar system processing to the processed reservoir on a 10^6 year timescale. The abundances were evolved and the the isotopic anomalies for Mo and Ba in the processed reservoir computed as the square root of the sum of mean square anomalies of the isotopes, relative to their final solar abundance. Fig. 1 shows the result (in units normalized to the magnitude of the largest anomaly). The greater nucleosynthetic heterogeneity of Mo means the processed reservoir is always more anomalous in Mo than Ba, thus, Mo isotopes will take a longer time to homogenize in the disk, and therefore, isotope anomalies will be larger than those identified for Ba in asteriods (e.g., carbonaceous chondrite parent body). This model can explain the diversity of Ba and Mo anomalies. A more complex system is currently being tested to account for the remaining isotope systems.

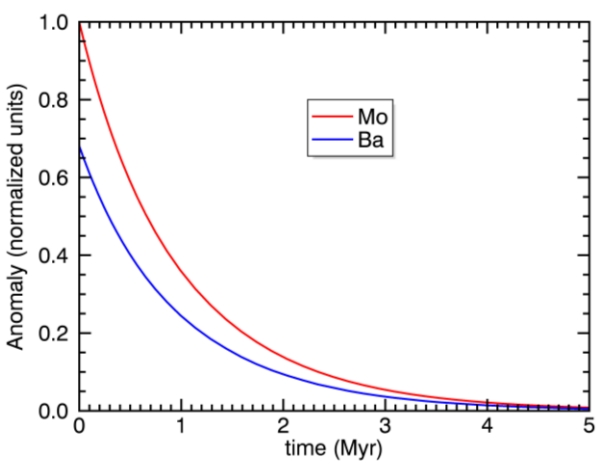

Fig. 1. Effective isotopic anomaly in Mo and Ba in a time-dependent three-reservoir mixing calculation.

The proposed scenario does not exclude the possibility that the magnitude of isotope anomalies may be inversely proportional to sample size. That is, larger isotope anomalies are detected in material sampling small fractions of the disk (e.g., CAIs), as opposed to smaller isotope anomalies that are found in whole rock meteorite samples due to dilution effects. Nor does this scenario exclude the potentially significant effects of thermal processing of presolar material resulting in selective destruction of certain isotope carriers and isotopic variability, e.g., [16] or late injection models e.g., [2]. All scenarios probably play a role in defining the relative isotope composition of inclusions and whole rock meteorite samples.

References:

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