BARIUM ISOTOPE ABUNDANCES IN METEORITES: IMPLICATIONS FOR EARLY SOLAR SYSTEM EVOLUTION

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Introduction

Various nucleosynthetic processes contributed to the abundances of the elements and their isotopes in the Solar System. How distinct nucleosynthetic materials were mixed to form the solar nebula is currently unclear. In this study, the distribution of Ba isotopes in 26 different whole rock meteorites (eucrites, diogenites, ordinary chondrites, Martian meteorites, enstatite chondrites and carbonaceous chondrites) was determined to constrain the level(s) of Ba isotope heterogeneity on the regional scale in the Solar System. Early papers [2-4] reported anomalous (i.e., isotope ratios that differ from terrestrial values) Ba isotopic composition in carbonaceous chondrites, however, these anomalies may have originated from incomplete dissolution of highly isotopically anomalous presolar grains (Fig. 1). A melting method using aerodynamic levitation, combined with CO_2-laser heating was used in our study to oxidize the primary presolar grain Ba isotope carrier (SiC) in carbonaceous chondrites, thereby enabling complete digestion of these samples (Fig. 2). Our Ba data are contrasted with a range of multi-isotope elements (Ti, Cr, Ni, Mo, Ru, Te, Ba, Nd, Sm, W and Os) to address the question as to why some elements are isotopically homogeneous on the bulk sample scale while other elements are isotopically variable.

Results

All samples, except for 6 carbonaceous chondrites, possess terrestrial Ba isotope compositions (Fig. 3). Allende (Smithsonian Reference Powder) and Vigarano (CV3), Cold Bokkveld and Mighei (CM2), Kainsaz and Lancé (CO3) have small, coupled ^{135}Ba and ^{137}Ba excesses (<40 ppm; Fig. 3). Importantly, the three aliquots of Allende processed (powdered, laser, furnace) produce the same sized isotope variations.

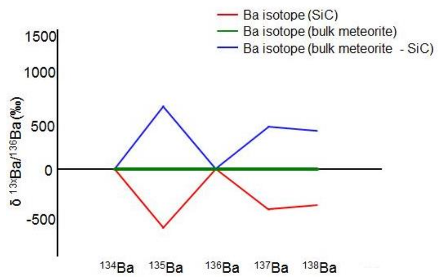


Fig. 1 The Ba isotope variation measured in individual SiC grains (data from [1]). Apparent nucleosynthetic anomalies [2-4] could originate from incomplete dissolution of these phases.

	Elements	Stellar model	Classical model
Non-anomalous isotopes			
	Sr	85	90
	Zr	83	82
	Te	17	19
	Ba	**81**	**92**
	Os	9.4	8.6
Anomalous isotopes			
	Mo	50	54
	Ru	32	37
	Sm	29	30
	Nd	56	59
	W	56	47

Table 1. The contribution (%) of the main s-component to the Solar elemental abundance (data from [5]).

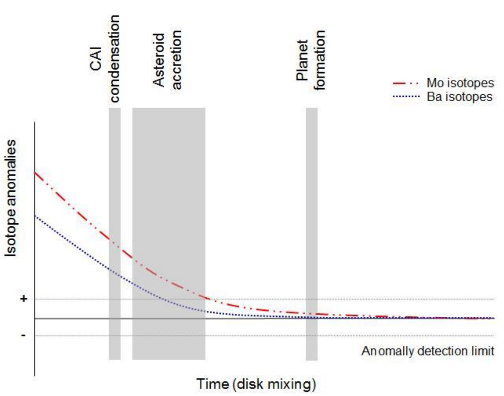


Fig. 4 A qualitative schematic shows how the number and proportion of nucleosynthetic processes which contribute to an element can influence the degree of isotope heterogeneity on the bulk sample scale.

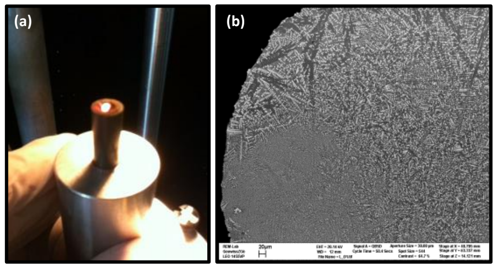
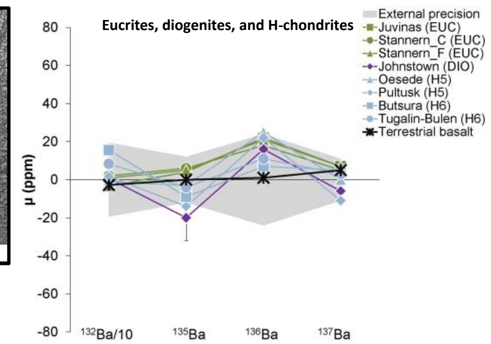
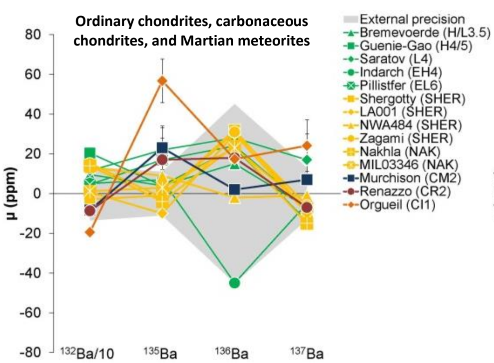


Fig. 2 (a) Melting method using aerodynamic levitation combined with a CO_2-laser. (b) A melted sphere (~10 mg powdered sample).





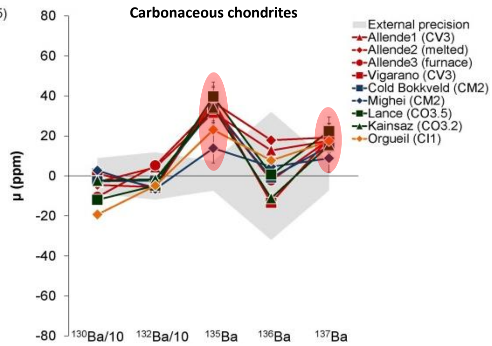


Fig. 3 The average Ba isotope ratios (in ppm) of individual filament measurements of thermally equilibrated meteorites and thermally unequilibrated meteorites. Data have been corrected for mass fractionation using the exponential law with the reference ratio $^{134/138}$Ba and are reported with $2\sigma_m$ uncertainties. Grey bands show the 2σ reproducibility of the terrestrial standard measured during the same analytical sessions as the samples. The data are presented using the μ notation (deviations in parts per 10^6 from the terrestrial standard.

Discussion

- After trialing laser fusion to achieve complete sample dissolution, no dependence on digestion method is observed in the Ba isotopic composition. This conclusion need not apply to other isotope systems (e.g., Ti and Mo).
- The isotope anomalies found here in carbonaceous chondrites are similar to, or slightly smaller, than previously reported [2-4]. For example, our data for Cold Bokkveld shows a ^{135}Ba ~38ppm and ^{137}Ba ~15ppm excesses, whereas [2] reported ^{135}Ba ~58 ppm and ^{137}Ba ~31 ppm variations.
- The isotopic variability of Ba in C-chondrites may reflect inadequate homogenization of the presolar component in these meteorites at the ~0.5 g sample scale, indicating larger samples are required to assess the scale of nucleosynthetic anomalies (~1 g).
- The largest differences are found in the abundance of ^{135}Ba. Given the observed small excesses in ^{137}Ba, most of the ^{135}Ba excess likely is due to a small s-process deficiency at the whole rock scale, but the magnitude of ^{135}Ba variation compared to ^{137}Ba variability also allows for the contribution of ^{135}Cs decay to ^{135}Ba. Cs/Ba could not be measured because of loss of Cs during laser heating.
- The Ba isotope data are compared with data for isotopically anomalous (e.g., Ti, Cr, Ni, Mo, Ru, Nd, Sm, and W) and non-anomalous elements (e.g., Te and Os) on the whole rock scale. Elements with small or undetectable isotopic anomalies (e.g., Ba, Te and Os) are dominated by one nucleosynthetic pathway (Table 1). However, if an element (e.g., Ti, Mo, Ru) comprises isotopes that have roughly equal proportions of s- and r-process nuclides, then large deviations in isotope abundances at the ε-level on the bulk sample scale are detectable. A possible explanation is that the time needed to homogeneously mix the different components in the disk is longer for those elements with near equal mixtures than for an element dominated by one or the other nucleosynthetic path (Fig. 4).

References: [1] Marhas et al., 2007. *Meteoritics Planet. Sci.* 42, 1077-1101, [2] Carlson et al., 2007. *Science* 316, 1175-1178, [3] Andreasen and Sharma, 2007. *Ap. J.* 665, 874-883, [4] Hidaka et al., 2003. *Earth Planet. Sci. Lett.* 214, 455-466 [5] Arlandini et al., 1999. *Ap. J.* 525, 886-900.