

**STABLE ISOTOPE ANOMALIES AND EARLY SOLAR SYSTEM CHRONOLOGY.** F. Albarède<sup>1</sup>, M. Ar-nould<sup>2</sup>, R.W. Carlson<sup>3</sup>, N. Dauphas<sup>4</sup>, T. Fujii<sup>5</sup>, S.B. Jacobsen<sup>6</sup>, Q. Yin<sup>7</sup>, and E.D. Young<sup>8</sup>, <sup>1</sup>Ecole Normale Supérieure, 69007 Lyon, France, <sup>2</sup>Univ. Libre de Bruxelles, 1050 Brussel, Belgium, <sup>3</sup>Dept of Terrest. Magnetism, Carnegie Inst., Washington D.C. 20015, <sup>4</sup>Dept of Geophys. Sciences, Univ. Chicago, Chicago, IL 60637, <sup>5</sup>Research Reactor Institute, Kyoto Univ., Osaka 590-0494, Japan, <sup>6</sup>Dept of Earth and Planetary Sciences, Harvard Univ., Cambridge, MA 02138, <sup>7</sup>Depart. Of Geology, Univ. California, Davis, CA 95616, <sup>8</sup>Dept of Earth and Space Sciences, UCLA, Los Angeles, CA 90095

The initial isotopic variability of elements in the Solar System (SoS) becomes a serious chronometric concern as soon as it compares in extent to radiogenic ingrowth or dominates it. With the noticeable exception of oxygen, the stable isotopes of elements such as Fe [1], Zn [2], Ni [3], Cd [4], Te [5] each define, at least to a few tens of ppm, single smooth mass fractionation lines among different planetary objects. This suggests that most elements are derived from a single SoS reservoir or that if there were several contributing sources, the material was efficiently mixed down to a very small scale. More recently, high precision analyses have resolved isotopic anomalies on specific isotopes of chronometric relevance such as <sup>54</sup>Cr [6, 7], <sup>62</sup>Ni [8], Nd, Sm [9, 10], Mo [11, 12], Ru [13], and Os [14-16] at the whole rock scale in carbonaceous chondrites. Most if not all of these effects seem to oppose even and odd isotopes. Though some of these anomalies (Os) may reflect inadequate sampling of insoluble presolar grains during analysis, the remainder clearly are present at the whole-rock scale. Regardless of their origin, the occurrence of anomalous isotopic compositions in carbonaceous chondrites indicates that this class of meteorite samples a different elemental mixture compared to other chondrite groups, differentiated meteorites, Moon, Mars and Earth.

The implication of this observation for the chronology based on short-lived radionuclides is not yet clear. Some of these anomalies may be due to nuclear field shift effects (NFS) during chemical processing of materials in the solar nebula [17, 18]. Although the NFS effect itself is reasonably well-understood [19] and may be seen as a residual mass bias analogous to mass-dependent fractionation, the processes behind it and the site at which fractionation is most effective remain poorly understood. The implications of the NFS effect for the distribution of short-lived nuclides in the solar nebula may be minimal because, if generated by chemical processes occurring in the solar nebula, the NFS effects may have no connection with the input and mixing of short-lived radionuclides in the SoS. NFS effects, however, may produce artifacts in the internal normalization procedure used for radiogenic chronometers because the odd/even effect and

the large deviations of nuclear radii away from magic numbers [17, 18] clearly affect the calculation of <sup>53</sup>Mn-<sup>53</sup>Cr [20], U-Th-Pb [21], and possibly the <sup>182</sup>Hf-<sup>182</sup>W ages, but their effect on the <sup>146</sup>Sm-<sup>142</sup>Nd system can probably be neglected.

On the other hand, if these anomalies are nucleosynthetic in origin, they offer the exciting perspective of comparing abundance observations and nucleosynthesis models for a very limited number of stellar sources, even possibly a single one. The aspects of the p-, s-, and r-processes of most direct relevance to the interpretation of these anomalies will be briefly and critically discussed [22-24]. The situation is in marked contrast with the one encountered when trying to understand the bulk SoS composition, which results from the mixture of a large variety of nucleosynthesis events, and consequently requires the modeling of the chemical evolution of the Galaxy. Measured anomalies may relate to presolar grains that have survived the process of incorporation into meteorites. In principle, these grains may be of interstellar or circumstellar origins. Such anomalies were first discovered in CAIs, in the rare FUN inclusions. In contrast to the presolar grains, the CAIs are considered to have formed in the SoS itself, even if some aspects of their origins remain puzzling.

The carrier phases of these isotopic anomalies could be associated with the influx of material that also brought in the short-lived radionuclides: the stable isotope variation may track variations in the abundance of these radionuclides with implications for the chronology based on the assumption of a homogeneous parent/daughter ratio throughout the SoS. This issue has already been discussed for the <sup>146</sup>Sm-<sup>142</sup>Nd system [9, 10], where it potentially is possible to track variations in the abundance of short-lived <sup>146</sup>Sm by examining variations in the abundance of the other p-process isotope, <sup>144</sup>Sm. Similar approaches could be used for other short-lived cosmochronometers that have multiple-isotope parent elements, for example Fe-Ni, Pd-Ag and Hf-W, but they are not applicable to systems with parent elements that are now monoisotopic (e.g. Al

and Mn). For systems with parent elements that are now monoisotopic (e.g. Al and Mn) this is not an option. Because isotopic variability is most prevalent in carbonaceous chondrites and their components, the most serious concern arises with comparisons of chronologies that relate to CAIs, where nucleosynthetic anomalies may play havoc with short-lived cosmochronometers.

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