ISOTOPICALLY NORMAL ZIRCONIUM IN MURCHISON HIBONITE 13-13:
IMPLICATIONS FOR A LINK BETWEEN THE e- AND r-PROCESSES

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Received 1993 December 30; accepted 1994 August 3

ABSTRACT

The isotopic composition of zirconium has been measured in Murchison hibonite grain 13-13 by ion microprobe mass spectrometry. Despite the highly anomalous Ti isotopic composition (27% excess of $^{50}$Ti), there is no evidence for any significant anomalies in the Zr isotopic abundances. This result is contrary to that expected based on a recent finding of $^{96}$Zr excesses correlated with $^{50}$Ti excesses in Allende refractory inclusions from which a link between the nucleosynthetic e- and r-processes was proposed. While Zr and Ti isotopic anomalies may exist together in Allende inclusions, it must be demonstrated more definitively that the Zr and Ti isotopic anomalies represent a genetic association rather than simply a mix of isotopically anomalous components with different degrees of dilution by normal solar material. If the $^{96}$Zr excess in the Allende inclusions is indeed a signature of the r-process, then the absence of a correlated excess of $^{50}$Ti with $^{96}$Zr in the Murchison hibonite indicates that the e- and r-processes are not always associated.

Subject headings: meteoroids — nuclear reactions, nucleosynthesis, abundances

1. INTRODUCTION

The interplay between theoretical constraints on nucleosynthesis and the measurement of isotopic anomalies in meteorites is appreciated to a larger extent than ever before. In large part this has been the result of the isolation of interstellar grains from meteorites in the laboratory and the recognition that these are products of circumstellar condensation which record the nucleosynthetic characteristics of their formation environment (Anders & Zinner 1993). The most definitive characteristics which identify these objects as xenocrysts to our solar system are the highly anomalous isotopic abundances that have been measured, particularly in SiC and graphite, and the carbonaceous compositions which require a formation environment with C > O.

However, not all objects with isotopic anomalies are of interstellar origin. Refractory inclusions from carbonaceous chondrites are much larger than the meteoritic interstellar grains and have characteristics which reflect their processing in the solar nebula. While oxygen isotopic anomalies with excesses in $^{18}$O of up to 5% are widespread, nonradiogenic anomalies in other elements are generally far smaller. This is illustrated in the nomenclature used to report isotopic anomalies where compositions are generally expressed as part-per-thousand (permil) deviations from the solar ratios.

For elements with only two isotopes, isotopic anomalies must be resolved beyond the range of physicochemical isotopic mass fractionation for the element. For an element with three or more isotopes, one isotope ratio can be sacrificed to monitor isotopic mass fractionation and the other ratios expressed as residuals relative to the normal solar ratios. For small effects, i.e., less than 1 permil, the recognition of an isotopic anomaly can be a function of the choice of the two isotopes used for the normalizing ratio.

Titanium has five isotopes, and despite the use of three different normalizing ratios from three different laboratories (Heydegger, Foster, & Compton 1979; Niederer, Papasousti, & Wasserburg 1981; Niemeyer & Lugmair 1981), it was soon apparent that there was a pervasive 1% excess of $^{50}$Ti in refractory inclusions. This enhancement in the heaviest isotope was then noted in a number of elements of the Fe group and was interpreted as being due to a small contribution of material that achieved some form of neutron-rich equilibrium prior to its admixture into the solar nebula. The correlations have been quantitatively addressed in the multiple-zone mixing (MZM) model of Hartmann, Woosley, & El Eid (1985) for which good agreement between $^{48}$Ca, $^{50}$Ti, and $^{54}$Cr excesses was obtained for a maximum neutron excess of around 0.15 for the Allende inclusion EK1-4-1.

Recently Harper et al. (1990, 1991) reported that they had measured $^{96}$Zr excesses (at a level of around 0.2%) in a suite of Allende inclusions and that these excesses are correlated with the $^{50}$Ti excesses (around 1%) in the same inclusions. Since the MZM model does not predict anomalies in $^{96}$Zr at the neutron excess required for the $^{50}$Ti anomalies, Harper et al. (1990, 1991) suggested that the $^{96}$Zr was produced in the r-process and hence the nucleosynthetic sites of the e- and r-processes are associated. Clearly such a link has implications for the theoretical treatment of the e- and r-processes. In order to test the extent of the $^{96}$Zr-$^{50}$Ti correlation, the Zr isotopic composition of Murchison hibonite 13-13 has been measured.

Murchison hibonite 13-13 has a special place in isotopic astronomy because it has the largest e-process-type isotopic anomalies in Ca and Ti yet measured with $\delta^{48}$Ca at +105% and $\delta^{50}$Ti at +273% (Ireland 1990). Ca and Ti in this hibonite grain have therefore been far less diluted by normal solar system material than for any of the several hundred refractory inclusions analyzed from various meteorites. It is to be expected that the isotopic compositions of the other Fe peak elements would also show the effects of the same nucleosynthetic process(es) but the abundances of Cr, Fe, Ni, and Zn are quite low because of their higher volatilities, and the effects of atomic isobaric interferences further hinder the ion microprobe measurements.

The 13-13 hibonite grain is $\approx$100 $\mu$m in the longest dimension and has been analyzed previously for rare-earth element concentrations as well as Mg, Ca, and Ti isotopic abundances.

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