

drites [5].

While Azzurra is comparatively young compared with other large craters on Ida, its weaker absorption band suggests that it is somewhat older and more weathered than the small crater. The background units, typical of much of Ida, are most optically mature. In the Azzurra region, there may be greater reddening of terrain with increasing distance from the central impact, perhaps indicating a degree of vertical or lateral mixing with mature materials near the thinner, distal edges of the ejecta blanket.

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FINDING THE RECIPE FOR IMPACT MELTS: THE SERENITATIS BASIN POIKILITIC MELT ROCKS. G. Ryder and K. R. Stockstill, Lunar and Planetary Institute, Center for Advanced Space Studies, 3600 Bay Area Boulevard, Houston TX 77058-1113, USA.

Impact melt rocks are complex mixtures of melt formed from a variety of rocks at the immediate target site plus fragmented material that is added as the melt is moved away from the target. Deciphering the components of a melt provides information on both the nature of the target and the processes of melt formation. In clast-poor melt rocks that are part of a homogeneous melt sheet there is no unique solution for the components. In terrestrial craters, field examination can provide direct clues, but for investigation of other planetary crusts this is not yet possible. Instead, the melts inversely provide information about the crust.

Poikilitic clast-bearing melt rocks from the Apollo 17 landing site form a cluster distinct from other melt rocks at that site and elsewhere. They have been almost universally accepted as produced in the Serenitatis basin-forming event [1], now reliably dated at 3.893 ± 0.009 (2 σ) Ga [2]. We obtained comprehensive chemical composition data using INAA and fused-bead (microprobe) analyses of 3-g splits of 18 different rocks with a range in grain sizes and chemistry, based in part on previous analyses [3]. We picked out larger clasts during homogenization to powder. Our analyses cluster more tightly than previous analyses. There is nonetheless variation outside analytical error representing interrock differences. The scatter of elements on binary plots shows that these rocks contain more than two end members.

We produced a correlation matrix on these analyses in a first stage of unraveling the components. The incompatible elements correlate strongly with each other and with Ti, and these elements are almost entirely in the melt phase, not in the clasts. This melt phase differs from that in the Apollo 17 aphanitic rocks, which have lower Ti-incompatible elements. The correlation matrix and binary element plots for the poikilitic rocks strongly suggest that both the melt phase and the clast populations differ somewhat among rocks. This is systematic in that the finer-grained rocks tend to have a more incompatible-element-rich bulk-rock composition, and thus are not just more rapidly cooled variants of coarse-grained melts. The lack of systematic variation of the major elements, including alumina, suggests that all target components were essentially basaltic or noritic in composition, lacking ferroan anorthosite, consistent with detailed analysis of plagioclase and mafic mineral fragments in these rocks [4]. The sum of the evidence suggests that these rocks are dominantly mixtures of small amounts of highly concentrated KREEP in a basaltic rock with varied noritic rocks forming the melt, plus fragments that were dominantly from noritic and gabbroic rocks, with some troctolites.

We are pursuing a least-squares-mixing-model approach to interpret the chemical variation of these rocks. We are making numerous runs, varying the end members in an attempt to see whether the components can be known igneous rocks, or reasonable facsimiles of them, or whether components unknown as samples must be used. We are further trying to establish whether the same components can provide reasonable fits for all the rocks, or whether different components for different rocks must be used. Combining our results with other features, such as the knowledge that four samples from varied units of a single boulder show almost as wide a chemical range as the entire set, should allow us to make inferences as to the nature of the crust in the target area as well as the production and crystallization of basin melts.

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POTASSIUM AND Mg ISOTOPIC STUDIES OF CM HIBONITES. S. Sahijpal¹, J. N. Goswami¹, A. M. Davis², L. Grossman³, and R. S. Lewis². ¹Physical Research Laboratory, Ahmedabad 380009, India, ²Enrico Fermi Institute, University of Chicago, Chicago IL 60637, USA, ³Department of Geological Sciences, University of Chicago, Chicago IL 60637, USA.

We have measured K and Mg isotopic compositions in a set of hibonites from the Murchison CM chondrite to look for the correlated presence (or absence) of ⁴¹Ca and ²⁶Al at the time of formation of the hibonite grains. Results obtained from an earlier study of two hibonite-bearing CAIs from the CV3 chondrite Allende (HAL) and Efremovka (E50) suggest such a correlation [1]. If confirmed, this will allow us to choose among the different possible scenarios suggested for the presence of these and other short-lived nuclides in the early solar system [2–6].

One of the analyzed samples (SH-7) was picked directly from an exposed surface of a Murchison fragment [7] and another (BB-4) was recovered using a freeze-thaw technique [8]. Additional hibonites (MUR-CH-A and B series) were hand-picked from HF/HCl insoluble residue of a large piece of the Murchison meteorite [9]. SH-7 is a millimeter-sized hibonite-rich inclusion [7] and a >100- μ m hibonite fragment has been selected for this study. BB-4 is a blue spheroidal object (~100 μ m diameter) composed of intergrown spinel and hibonites [8]. The other two sets of samples MUR-CH-A1 to A5 and (MUR-CH-B1 to B8) are either platelet-type irregular thin chips of hibonites or hibonite-bearing spheroidal light- to medium-blue objects. Earlier Mg isotopic studies of SH-7 and BB-4 [7,8] suggested that the former is devoid of ²⁶Mg excess while the latter has excess ²⁶Mg with an initial ²⁶Al/²⁷Al close to the canonical value of 5×10^{-5} .

The Mg and K isotopic compositions are measured using a Cameca ims-4f ion microprobe following procedures described elsewhere [6]. The measurement of the ⁴¹K signal is difficult due to the presence of the unresolved doubly charged interference [⁴⁰Ca⁴²Ca]⁺⁺ and the possibility of contribution from scattered ions from the [⁴⁰Ca H]⁺ peak [6]. In the present study, interference from the hydride peak has been reduced below detection level by mounting individual hibonites in millimeter-sized epoxy beads on a metal disk for analysis. This has reduced the (MH)^{+/M⁺} signal by more than one order of magnitude than that for standard epoxy disks used for thin section studies of CAI samples. Measurements of the isotopic compositions as well as the magnitude of the doubly charged interference were done at the same spot in the following sequence: Mg isotopic measurement with low primary beam current (~1 nA), followed by K isotopic studies at a higher current (~2.5 nA), and finally determination of the magnitude of the doubly charged interference, through measurement of the [⁴⁰Ca/⁴³Ca]⁺⁺ signal at mass 41.5, at an even higher beam current (~5 nA). Energy centering was performed both before and after analysis in each case to ensure that there was no significant shift in the energy distribution of the secondary ions during the analysis duration.

So far we have analyzed three samples from the MUR-CH-B series, as well as SH-7 and BB-4. All three hibonites from the B series were of platelet type (thin irregular chips) and are devoid of ²⁶Mg excess. The inferred initial ²⁶Al/²⁷Al in these three cases are $<6.0 \times 10^{-6}$, $<6.7 \times 10^{-6}$, and $<10^{-6}$ respectively. The ⁴⁰Ca/³⁹K ratios in these hibonites are 1.5×10^5 , 2.4×10^6 , and 3×10^6 respectively, and all of them have ⁴¹K/³⁹K ratios close to the normal value of 0.072. The data for the two grains with high ⁴⁰Ca/³⁹K ratios yielded initial ⁴¹Ca/⁴⁰Ca values of $<4 \times 10^{-9}$ and $<10^{-8}$ respectively. Our studies of the Mg isotopic composition of SH-7 confirmed the absence of the ²⁶Mg excess reported earlier [7]; our data suggest an initial ²⁶Al/²⁷Al value of $<9 \times 10^{-6}$ for this sample. There is also no evidence for ⁴¹K excess in SH-7, and the K isotopic data yield an initial ⁴¹Ca/⁴⁰Ca value of $<3 \times 10^{-9}$. Hibonites from BB-4 show clear evidence for ²⁶Mg excess with an initial ²⁶Al/²⁷Al value of $(6.0 \pm 1.5) \times 10^{-5}$, which is consistent with the result obtained in the earlier study [8]. However, the ⁴⁰Ca/³⁹K ratios in several hibonites analyzed so far from this sample are rather low ($\leq 5 \times 10^5$). The K isotopic analysis of the hibonite with the highest ⁴⁰Ca/³⁹K ($\sim 5 \times 10^5$)

yielded a $^{41}\text{K}/^{39}\text{K}$ ratio of 0.077 ± 0.004 ($2\sigma_m$), indicating the possible presence of excess ^{41}K . Note that this value is consistent with the expected value for an initial $^{41}\text{Ca}/^{40}\text{Ca}$ of -1.4×10^{-8} , inferred from analysis of Efremovka CAIs [6,10].

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EVIDENCE FOR ISOTOPIC HETEROGENEITY OF Zr IN NATURE: PRETERRESTRIAL RECORDS. S. K. Sahoo and A. Masuda, Department of Chemistry, University of Electro-Communications, Chofu, Tokyo 182, Japan.

It is widely believed that, in general, the isotopic abundance ratios of elements do not show variations in the Earth. The major motivation of our present work is the uncertain hypothesis that, except for the mass-dependent fractionation and the radiogenic effect on the Earth, any element must have been isotopically homogenized during the process from nucleosynthesis to the formation of the Earth.

Zirconium, one of the most refractory elements, comprises five stable isotopes with mass numbers 90, 91, 92, 94, and 96. Zirconium is a suitable element for *s*-process studies since ZrO is a predominant feature in the *S* stars [1] and ^{90}Zr is neutron magic. Out of five stable isotopes, only ^{96}Zr does not lie on the *s*-process chain. In addition, ^{92}Zr , although unstable to β -decay, has a long half-life (2×10^6 yr) compared to timescales for probable interior changes in red giants.

The previous results [2–5] are not necessarily precise enough. We have taken elaborate precautions against the potential contamination of Mo and repeated long-term measurement. We attained the high precision of 0.002–0.007% (RSD) for Zr isotopic ratios measurement using a VG Sector 54-30 TIMS. In order to confirm the reproducibility of this technique, Zr of six commercially reagents and Zr separated from two meteorites were studied. Isotopic ratios were corrected based on linear mass discrimination by normalization using $^{94}\text{Zr}/^{90}\text{Zr}$ ratio. Cica-Merck Zr atomic-absorption spectrometry-grade solution, further purified by us, has been used as the standard material. Relative aberration patterns have been plotted in terms of ϵ units

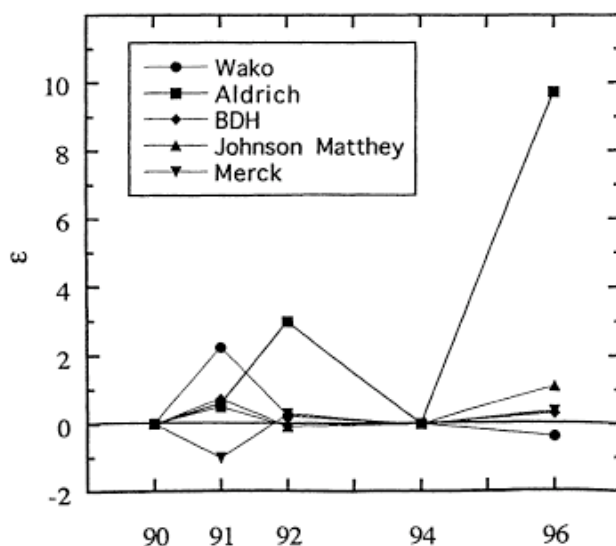


Fig. 1. Aberration of isotopic abundance ratio, $^{12}\text{Zr}/^{90}\text{Zr}$, relative to Cica-Merck based on the normalization pair ^{90}Zr and ^{94}Zr .

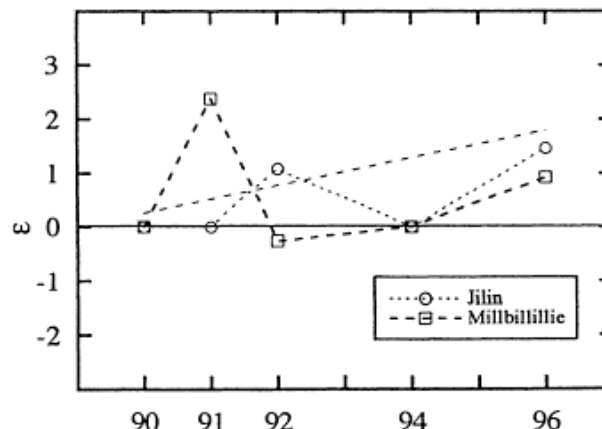


Fig. 2. Relative aberration to Cica Merck for meteoritic Zr.

and in normalization with $^{94}\text{Zr}/^{90}\text{Zr}$ for all the Zr standard solutions (Fig. 1). Aberration of isotopic abundance ratio $^{12}\text{Zr}/^{90}\text{Zr}$ for Zr extracted from two meteorites, Jilin and Millbillillie, relative to Cica-Merck is shown in Fig. 2.

It has been observed that ^{91}Zr and ^{94}Zr show a special difference with reference to the available data. The isotopic composition of Zr in Aldrich chemicals show a clear nonlinear anomaly at ^{94}Zr when normalizing against $^{90}\text{Zr}/^{90}\text{Zr}$. The aberrations for ^{92}Zr are nearly comparable with the empirical errors except for the Jilin meteorite, while those for ^{96}Zr are not always negligible.

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SIGNIFICANCE OF ANCIENT “IMPACT-MELT ROCKS” FOR THE ORIGIN OF CHONDRULES. I. S. Sanders, Department of Geology, Trinity College, Dublin 2, Ireland.

The origin of chondrules remains a major unresolved issue in our understanding of the early solar system [1]. According to conventional wisdom, chondrules were formed by the flash-melting of preexisting dust clumps in the solar nebula, before the accretion of planetesimals [2,3]. However, the conventional view is under threat on at least three counts. First, “planetary” igneous rock clasts have been identified in chondrites [e.g., 4], suggesting that the chondrule population was mixed with fragments of disrupted planetesimals that had already undergone magmatic fractionation. Second, chondrules appear younger, by one or more million years, than calcium-aluminum-rich inclusions (CAIs), which are the oldest solar system objects known [5]. Since the earliest planetesimals probably grew within about 100 k.y. of CAIs [6], it seems that planetesimals were a well-established feature of the solar system by the time chondrules arrived on the scene. Third, the local abundance of otherwise rare merrihueite-bearing chondrules in the Mesö Madaras chondrite led [7] to conclude that chondrules must have formed in close proximity to the planetesimal where they came to reside. In attempting to reconcile such awkward evidence with conventional wisdom, Wood [1], in a somewhat defeatist manner, concluded that the process of chondrule formation was probably so complex that the truth of it may never be known, or might even not be worth seeking.

A small, resolute, and growing number of scientists refute conventional wisdom and, like Urey [8], regard chondrules as frozen droplets of melt ejected during collisions between planets or planetesimals [9–11]. Although this concept is mechanically and energetically implausible with solid planetesimals [12], it would seem to work well if one or both planetesimals were molten, or partially molten, at the time of impact. In this molten-planetesimal model [11], low-velocity collisions cause impact “splashing,” and much of the resulting spray falls back under gravity as chondrules. The preferred cause of melting is short-lived radioactivity that, during the first