Ti ISOTOPES IN ALLENDE INCLUSIONS AND UNEQUILIBRATED CHONDRITE CHONDRULES. S. Niemeyer* and G. W. Lugmair, Chemistry Dept., B-017, Univ. of Calif. San Diego, La Jolla California 92093.

The measurement of isotopic compositions of Ti from Allende FUN inclusions by Niederer et al. [1] revealed clearly resolvable anomalies for all isotopes not used for normalization, with the largest anomalies occurring at 50Ti. Subsequent reports by Niemeyer and Lugmair [2] and Niederer et al. [3] clearly established that nearly all normal Allende inclusions also contain anomalous Ti. The dominant anomaly is also at 50Ti with excesses on the order of 1%. Thus, Ti is the first non-noble-gas element studied since oxygen for which nuclear isotopic anomalies are common in Allende inclusions. In this report, we first focus on Allende fine-grained inclusions and then widen our search for Ti anomalies to include chondrules from unequilibrated chondrites.

In our initial report [2], all four coarse-grained Allende inclusions gave very similar 50Ti excesses, defining an average $\varepsilon(50/46)$ value of $+8.2 \pm 1.2$ ($\varepsilon$ denotes deviation from a Ti metal standard in parts in 10$^4$). In contrast, the only fine-grained inclusion in that study yielded a very much greater 50Ti excess of nearly 3%. This prompted further investigation to determine whether such enhanced excesses are a common feature of fine-grained inclusions. Experimental procedures are the same as those described elsewhere [4]. Isotopic compositions for five fine-grained inclusions are shown in Fig. 1; plotted errors are 95% C.L. Three of the inclusions are pink and two are white; the white inclusion 7R-44A-1 is purely spinel. Samples 7R-41, 3673 and 7R-44A-1 are described in [4]; the remaining two inclusions have not yet been characterized mineralogically.

Inclusion 7R-41 is the same fine-grained sample referred to above, except previously [2], it was designated as 14d-2. Reanalysis of this special inclusion was deemed especially important, since the two previous analyses differed substantially, although not significantly. The mean composition from these two prior measurements is $\varepsilon(47/46) = -2.5 \pm 1.3$, $\varepsilon(48/46) = +0.1 \pm 3.8$, and $\varepsilon(50/46) = +27.7 \pm 5.8$. A new aliquot of the same pyroxene separate was analyzed for this study, and the $\varepsilon(50/46)$ value of $+28.8 \pm 2.3$ gives excellent agreement with the previous results, but with a much smaller uncertainty. In [4] we discussed Ti isotopic systematics for normal and FUN Allende inclusions plus terrestrial samples. We concluded that only 3 distinct components were imperative, although the unusual composition of 7R-41 hinted at a need for a fourth component. The more precise results obtained here strengthen considerably the case for a fourth component. For a 4-component mix, a mono-isotopic 50Ti contribution is allowed; such a contribution is not permitted in a 3-component system. This possibility may be important since nucleosynthetic considerations suggest that the processes in a star where the anomalous 50Ti might have been synthesized do not co-produce other Ti isotopes.

The other two pink fine-grained inclusions shown in Fig. 1 have much smaller 50Ti excesses, but the anomalies are still greater than the average for coarse-grained inclusions. In contrast, the two white fine-grained inclusions give close agreement with coarse-grained inclusions. The interpretation of this apparent trend is not yet clear. Perhaps the magnitude of the 50Ti anomaly reflects the mineralogy, e.g. spinel carries a smaller anomaly than pyroxene, but such an interpretation requires further mineralogical examinations. We note that the three fine-grained inclusions discussed in [3] all clustered about an $\varepsilon(50/46)$ value of $+10$, but the absence of mineralogical information for these inclusions impedes an interpretation.

All fine-grained inclusions in Fig. 1 are very similar for isotopes other than 50Ti. In general, $\varepsilon(47/46)$ lies more than 2$\sigma$ below zero, and $\varepsilon(48/46)$ is
positive but close to within 2σ of the normal. The greatest deviant from this pattern is Alli PF-A, but, even in this case, the mean ε(47/46) lies nearly 2σ below zero and the excess ε(48/46) is just greater than 2σ. The similarity of the isotopic patterns allow us to average all five inclusions to obtain mean values of ε(47/46) = -2.4 ± 0.6 and ε(48/46) = +0.9 ± 0.6. The 48/46 average is apparently significant at the 3σm level, yet it is not clear that this deviation is a real effect, since it is still less than 1 ε-unit, and the error on the normal itself is 0.5 ε-units. But the deficit for 47/46 is nearly 3 times greater. Furthermore, it matches very closely a previous mean value [4], thereby supporting our previously somewhat tentative claim that these deficits are not artifacts. Thus, we conclude that in addition to the dominant 50Ti excesses, normal Allende inclusions also contain other smaller anomalies. It is difficult to ascertain whether the 50 and 47 anomalies are correlated. However, comparison of 7R-41 and ALK100 FGWI indicates a decoupling of these anomalies, since the 50 excesses differ by more than a factor of 3 while the 47 deficits are virtually identical.

Now that Ti isotopic anomalies are well established for Allende inclusions, an important next step is to investigate whether other meteorites carry anomalous Ti. Recent oxygen isotopic analyses of chondrules from unequilibrated chondrites [5,6] revealed that instead of falling within the respective chemical groups of their host-chondrites on the conventional 3-isotope oxygen plot, chondrules from unequilibrated chondrites generally lie on a single 16O mixing line which passes through the ordinary chondrite groups. The chondrules, more deficient in 16O than their hosts, are the most 16O-poor meteorite samples yet measured, and thus are complementary to the Allende inclusions which are 16O-rich. Thus, if there is any relation between Ti and 0 nuclear anomalies in meteorites, one expects these chondrules to show 50Ti deficits. The Allende inclusions, however, yield about order-of-magnitude greater oxygen anomalies than the chondrules, and thus even if a relation between Ti and 0 exists, the 50Ti deficits in the chondrules may not be resolvable with current experimental precisions. The Ti isotopic analyses for 3 chondrules are shown in Fig. 2. Duplicate analyses of a Dhajala chondrule give no evidence for a 50Ti anomaly, and other isotopes are also normal within uncertainties. In contrast, Ch1 from Chainpur gives a 3.5 ε-unit deficit. The second analysis ran very poorly, hence, the large errors, but the results agree very well with the first, more precise measurement. We note that all previous standards and terrestrial rocks measured in this laboratory agreed within 2σ with the normal 50/46 ratio, and only in one very early analysis was a more than 2 ε-unit deficit observed. Also, standards measured between chondrule samples gave reproducibly normal results. This good reproducibility and the close agreement for the two Chainpur Ch1 analyses support the reality of the 50Ti deficit. A second Chainpur chondrule shows a slight 50Ti deficit, but this small deviation cannot be termed significant since the 95% C.L. is comparable. Both Chainpur chondrules are normal at 47/46 and 48/46.

An important petrographic difference between Chainpur and Dhajala is that the degree of unequilibration, as determined from the extent of matrix recrystallization, is very much greater for Chainpur than Dhajala [7]. But it is unlikely that the metamorphic heating affected Ti carried by the chondrules, and the oxygen compositions of Dhajala chondrules [8] reveal the same isotopic effects as the more highly unequilibrated chondrites. Thus, the absence of a 50Ti deficit in the Dhajala chondrule and the suggestion of such deficits in the two Chainpur chondrules creates an ambiguous situation. We intend to pursue this problem by analyzing chondrules from other unequilibrated chondrites, with an emphasis on the more highly unequilibrated meteorites.
Ti Isotopes in Allende Inclusions

S. Niemeyer and G. W. Lugmair

References:


This research was supported by NASA NGL 05-009-150.

Present address: University of California, Lawrence Livermore Laboratory, Livermore, California 94550.