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Ti ISOTOPE ABUNDANCES IN WHOLE METEORITES

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Previous work has identified the presence of nonlinear isotope effects for Ti in CM and CV chondrites (NPW, 1984, 1985; KPW, 1985; Niemeyer and Lugmair, 1984). We report new measurements on CO and CV meteorites, two chondrites (Parnallee, LL3; Parsa, E4) and a shergottite. Since our earlier reports (NPW, 1985; KPW, 1985) on the absolute Ti composition, we have concentrated on the measurement of Ti abundances normalized to $^{46}Ti/^{48}Ti$, in order to establish first the extent of nonlinear effects. Samples of the whole meteorites were taken for Ti and Cr. Precision for Ti isotope abundances is $\leqslant 1$ ϵu for all ratios. The two CO meteorites show distinct and well resolved excesses in ^{50}Ti and establish the presence of distinct ^{50}Ti effects also in this subclass of carbonaceous meteorites, at the level of 5 ϵu. No effects are found for ^{49}Ti or ^{47}Ti. Ordinary chondrites and achondrites show no Ti nonlinear isotope effects. These observations imply: a) Nonlinear effects in Ti are common in all classes of carbonaceous chondrites, except CI. b) The nonlinear Ti effects in carbonaceous meteorites (CM, CO, CV) are smaller (factor of ~ 10) than the nonlinear isotope effects in oxygen (e.g. Clayton *et al.*, 1976). c) Any Ti effects in ordinary chondrites and achondrites correlated with exotic oxygen may be below the current precision of 1 ϵu for Ti.

If the Ti nonlinear effects in whole meteorites are due to the admixture of multiple exotic components, then the normal composition of ordinary chondrites and achondrites requires the admixture of components with both positive and negative $\epsilon(50/48)$, the latter having been identified only in the FUN inclusion C-1 and some hibonites in Murchison (Hutcheon *et al.*, 1983). The effects in CM, CO, CV chondrites indicate the relative depletion in them of components with $\epsilon(50/48) < 0$. If the Ti nonlinear effects are due to the addition of exotic components to a well-defined, normal, solar system composition, then the identification of these components is class specific, at present found only in the CM, CO and CV classes. If the endemic effects in ^{50}Ti are due to modification of normal Ti, this process would also be restricted to the CM, CO, and CV precursor materials. The existence of components with very large (1000 ϵu) isotope effects in ^{50}Ti (Fahey *et al.*, 1985) may permit the propagation of small, endemic effects in ^{50}Ti from only a small amount of exotic materials, making the identification of these exotic materials elusive. The observation of more modest ^{50}Ti effects (10 ϵu) in typical CAI indicates that Ti in CAI may already be significantly diluted relative to effects in some ultra-refractory components.

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Table 1
Deviations, in parts in 10^4, from the standard compositions of terrestrial Ti normalized to $^{46}Ti/^{48}Ti$. Ti concentration in ppm, except where percent is marked.

Sample [class]	Weight [mg]	Ti conc.	Normalized to $^{46}Ti/^{48}Ti$ $\epsilon 47$	$\epsilon 49$	$\epsilon 50$
Coolidge [CV4]	93	792	$0.1 \pm .05$	-0.4 ± 0.8	3.6 ± 0.7
Kainsaz [CO3]	103	—	0.9 ± 0.6	0.3 ± 0.8	4.9 ± 0.9
Ornans [CO3]	99	661	0.4 ± 0.8	0.5 ± 0.9	5.6 ± 1.2
Parnallee [LL3]	97	564	0.5 ± 0.6	-0.2 ± 0.9	0.8 ± 0.8
Parsa [E4]	103	407	0.9 ± 0.9	-0.4 ± 0.9	0.6 ± 1.2
Shergotty [Sh]	49	0.43%	0.6 ± 0.4	0.2 ± 0.5	0.8 ± 0.8

AN ANNEALING STUDY OF DHAJALA, AN H3.8 CHONDRITE, AND APPLICATION TO THE PALAEOTHERMOMETRY OF METEORITES

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The thermoluminescence emission characteristics of a meteorite are strongly dependent on the metamorphism it has suffered (Sears and Weeks, 1983). When the temperature of the maximum emission (peak temperature) is plotted against the width of the peak at half maximum emission (Fig. 1), two clusters are produced and it is possible to move a meteorite normally plotting in the lower cluster into the higher by annealing above 700°C (Guimon *et al.*, 1984). Similar behavior is displayed by terrestrial albite in which these changes were associated with the order-disorder transformation (Pasternak, 1978). Individual chondrules also plot in two clusters, bright chondrules have TL curves with narrow peaks at 100°C and dull chondrules produce TL curves with broad peaks at 200°C (Sears *et al.*, 1984).

In the present work we annealed Dhajala, a meteorite which naturally plots in the lower right hand corner of the high temperature cluster, to determine the effect of annealing above the transformation temperature. The meteorite was annealed for 10 hours at various temperatures in nitrogen at atmospheric pressure. The peak temperature increased steadily while the peak width increased abruptly after the annealing treatments so that the annealed samples moved to the upper right extreme of the high temperature cluster. We conclude that a lower temperature component of the Dhajala phosphor still makes a significant contribution even though this meteorite plots in the high temperature cluster. We suggest that Dhajala cooled sufficiently slowly for some crystallization to occur below the transformation temperature and that the low temperature component is located in the bright chondrules which are also higher in Ca and were probably able to equilibrate to lower temperatures than the dull chondrules.