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INAA OF CAIs FROM THE MARALINGA CK4 CHONDRITE: EFFECTS OF PARENT BODY THERMAL METAMORPHISM;

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Maralinga is an anomalous CK4 carbonaceous chondrite which contains numerous Ca-, Al-rich inclusions (CAIs) unlike the other members of the CK group [1]. These CAIs are characterized by abundant green hercynitic spinel intergrown with plagioclase and high-Ca clinopyroxene, and a total lack of melilite [2]. We have used Instrumental Neutron Activation Analysis (INAA) to further characterize the meteorite, with special focus on the CAIs. High sensitivity INAA [3] was done on eight sample disks about 100-150 μm in diameter obtained from a normal 30 μm thin section with a diamond microcoring device [4]. The CAIs are enriched by 60-70X bulk meteorite values in Zn, suggesting that the substantial exchange of Fe for Mg that made the spinel in the CAIs hercynitic also allowed efficient scavenging of Zn from the rest of the meteorite during parent body thermal metamorphism. Less mobile elements appear to have maintained their initial heterogeneity.

Analytical. Because the samples are too small to weigh accurately (0.1-1.2 μg), their masses have been estimated from the measured amounts of Fe and estimates of FeO content from microprobe work [1,4]. Thus, absolute abundances are uncertain by about ±10%, but elemental ratios for well-determined elements are more accurate. The low abundances of many interesting trace elements in chondritic meteorites make them less than ideal subjects for INAA even when abundant material is available, and the two sigma upper limits for a number of elements under the conditions used here were less than chondritic values. Nonetheless, positive compositional anomalies would have been readily visible even for some unfavorable elements, and the "good" INAA elements offer some interesting insights. This was essentially a feasibility study of a few drilled samples, and would benefit from microprobe analyses of the specific areas sampled.

Results. The disk drilled from one of the two spinel-rich inclusions broke into three pieces (about 0.6, 0.3, and 0.3 μg) which were analyzed separately. Considerable variations in composition are apparent (see Table), with the largest variations observed in Sc (8X), Ir (25X) and Au (about 6X). The sample highest in Ir (about 3 ppm) had the lowest Au value (20 ppb). Refractory metals (including Re and Rh, which were observed but not quantified) show considerable variability at this scale, presumably reflecting trace sulfides, etc. [5]. Sm, the only rare earth element detected in all three aliquots, varied by a factor of 3, as did Na, while Cr, Co, Ni, and Zn varied by about 30% from highest to lowest. The other green spinel inclusion has similar contents of transition metals and somewhat higher contents of rare earths, Ca, and K. The most striking compositional feature of these green inclusions is their very high Zn contents (2930-5510 ppm, averaging about 4000 ppm). Also analyzed were a sample of matrix, a variety of chondrules and other inclusions, a large magnetite grain, and a sample of a hydrated iron oxide weathering vein. The matrix sample resembles previous bulk analyses of Maralinga [6,7], but is slightly lower in Fe, Cr, Co, and Ni (perhaps in part due to normalization to the fairly low matrix FeO value determined by defocused electron beam analysis [1]), and higher in Na. The Sc content of the matrix sample is only about half the bulk value, and may simply represent sampling of matrix in a low-Sc region distant from any high-Sc inclusions. Another curious feature of the matrix analysis is 4.3 ± 0.6 ppm tungsten, presumably due to sampling of a region once containing tungsten-rich minerals. Three textural varieties of olivine-rich chondrules were sampled, and their analyses are unremarkable, except that one has quite high Sc.

Discussion. Variability in Sc (note the vertical trends in the figure) may be simply a problem in sampling the clinopyroxene that is the phase richest in Sc, or may mean that inhomogeneities arising from high-Sc CAIs have not been fully erased during metamorphism. The 4000 ppm average Zn content of the CAIs is 40X the average CK chondrite value [6], and 60-70X the bulk Maralinga value of 65 [7] or 57 ppm [6]. If all the Zn in the meteorite were in the green inclusions, they could comprise no more than ~1.5% of the sample, a value which is in surprisingly good agreement with the estimated abundance of CAIs obtained using the petrographic microscope [1]. Of course, substantial amounts of Zn are also observed in our matrix and chondrule analyses, and it is quite possible that the aliquots from which the bulk samples were taken were poor in CAIs. Still, the Zn enrichment in spinel is remarkable. Volatile Zn should have been absent from the original CAIs, and must have been transported efficiently from a sizable volume of meteorite in order to attain the levels observed. Homogeneous olivine compositions throughout the meteorite attest to the efficiency of redistribution of divalent Mg, Fe, and Ni. Also, matrix plagioclase grains are strongly zoned, with ~An_{80} rims surrounding cores of ~An_{40}, suggesting that extensive Ca diffusion occurred during thermal metamorphism [8]. Additional petrographic evidence of Ca diffusion is the replacement of perovskite by ilmenite in several of the inclusions. Thus, redistribution of Zn is to be expected. Less mobile species such as Al and Si could not have moved substantially without obliterating much of the texture. Perhaps other more highly charged species such as Sc have also experienced limited mobility, and could help explain the small-scale variability observed in this work.

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	CALCIUM-, ALUMINUM-RICH INCLUSIONS				MATRIX	CHONDRULES			
	A1	A2	A3	B		olivine	fine grained	barred	
	0.60 ug.	0.28 ug.	0.30 ug.	0.76 ug.	0.44 ug.	0.43 ug.	0.16 ug.	1.09 ug.	
Na2O	0.1050 ±0.0018	0.200 ± 0.003	0.442 ± 0.007	0.347 ± 0.005	0.420 ± 0.007	0.0387 ±0.0008	0.0867 ±0.0016	0.258 ± 0.004	Na2O
FeO	15.01 ± 0.18	15.05 ± 0.20	15.01 ± 0.19	15.03 ± 0.18	27.0 ± 0.3	30.1 ± 0.3	29.9 ± 0.4	30.2 ± 0.3	FeO
Sc	6.58 ± 0.09	16.9 ± 0.2	54.0 ± 0.6	23.3 ± 0.3	5.83 ± 0.09	8.40 ± 0.11	8.44 ± 0.13	33.2 ± 0.4	Sc
Cr	2800. ± 40.	1980. ± 30.	2130. ± 30.	2640. ± 40.	2820. ± 40.	1169. ± 16.	1910. ± 30.	2400. ± 30.	Cr
Co	564. ± 7.	689. ± 8.	747. ± 9.	725. ± 9.	332. ± 4.	456. ± 5.	397. ± 5.	457. ± 5.	Co
Ni	3710. ± 70.	4530. ± 130.	5040. ± 130.	4450. ± 90.	3490. ± 90.	4800. ± 100.	3760. ± 140.	4920. ± 90.	Ni
Sm	0.097 ± 0.013	0.178 ± 0.017	0.32 ± 0.03	0.388 ± 0.017	0.132 ± 0.018	0.210 ± 0.011	0.096 ± 0.012	0.485 ± 0.014	Sm
Ir	0.120 ± 0.014	3.2 ± 0.3	0.112 ± 0.015	4.2 ± 0.4	0.137 ± 0.016	0.31 ± 0.03	0.16 ± 0.02	<0.04	Ir
Au	0.047 ± 0.005	0.019 ± 0.009	0.124 ± 0.012	0.013 ± 0.006	0.033 ± 0.007	0.012 ± 0.005	0.020 ± 0.006	<0.019	Au
Zn	2930. ± 50.	3590. ± 80.	3890. ± 70.	5510. ± 80.	50. ± 20.	72. ± 15.	<80.	79. ± 12.	Zn