

REFRACTORY INCLUSIONS IN MURCHISON: CHEMISTRY AND MG ISOTOPIC COMPOSITION. T. Tanaka^{1,2}, A.M. Davis³, I.D. Hutcheon⁴, M. Bar Matthews^{1,5}, E. Olsen^{1,6}, G.J. MacPherson¹ and L. Grossman^{1,4}. ¹Dept. of the Geophysical Sciences, University of Chicago, Chicago, IL 60637. ²On leave from Geological Survey of Japan. ³James Franck Institute, University of Chicago. ⁴Enrico Fermi Institute, University of Chicago. ⁵On leave from Geological Survey of Israel. ⁶Field Museum of Natural History, Chicago, IL 60605.

Refractory inclusions have been known from C2 chondrites like Murchison for years [1], but relatively little chemical or isotopic work has been performed on them, primarily because their scarcity and small size compared to those in Allende make them more difficult to find, extract and make measurements on. What work has been done in these areas suggests that the C2 inclusions are every bit as diverse and interesting as their counterparts in C3 chondrites and may contain information about early solar system processes which has not yet come to light from studies of Allende. In a trace element study [2] of a mixture of two spinel-hibonite (SH) inclusions [1,3], the simultaneous enrichment in refractory lithophiles and refractory siderophiles characteristic of Allende coarse-grained inclusions was found [4], together with what was inferred to be a Group II REE pattern typical of Allende fine-grained inclusions [5]. In an ion microprobe (IMMA) study of Mg isotopic compositions of Murchison hibonite, Macdougall and Phinney [6] claimed that a single 120 μm crystal, MH88, from the matrix had no excess ^{26}Mg in spite of $^{27}\text{Al}/^{24}\text{Mg} > 88$, that Mg was mass-fractionated in a 100 μm polycrystalline fragment from an ~ 200 μm nearly pure hibonite inclusion and that there was a suggestion of excess ^{26}Mg correlated with $^{27}\text{Al}/^{24}\text{Mg}$ in an ~ 500 μm SH inclusion, MH96.

In a companion paper [7], we demonstrated a technique for recovering large numbers of refractory inclusions from Murchison and described the petrographic and mineralogical characteristics of several of them. In the present paper, the polished surfaces of two of those inclusions, a blue chip (DJ-1) and a coarse-grained, melilite-bearing inclusion (MUM-1) were studied by IMMA. In addition, we determined by INAA the concentrations of 32 elements in a blue spherule (BB-3) similar to two (BB-1 and BB-2) described in [7]. We also present RNAA data for the SH inclusion, M-11, previously studied by INAA in [3].

BB-3 is a blue sphere, 170 μm in diameter and 9.7 μg in mass. From major elements, it contains $\sim 40\%$ hibonite, 55% spinel and 5% perovskite, similar to BB-1 and BB-2 [7]. It has a Group III REE pattern: uniformly enriched in all REE by a factor of 40 relative to C1 chondrites, except for Eu and Yb which are enriched by factors of 17 and 21, resp. Ta, Th, Hf and V are enriched to the same degree as most of the REE. Sc, Ir and Ru have lower enrichment factors, ~ 30 . Refractory trace element enrichment factors are twice as great in BB-3 as in Allende coarse-grained inclusions, suggesting that the trace elements are concentrated into a smaller fraction of the total condensable matter in blue spherules than in Allende inclusions, as inferred in [7] on the basis of their mineralogy.

A remarkable feature of BB-3 is the extraordinary enrichment factor for Os, ~ 60 , twice as high as for Ir and Ru. We note that M-11, the only other refractory inclusion from Murchison analysed, also has an Os/Ir ratio higher than the C1 value, by a factor of 1.6 [2], but this inclusion also has a higher Ru/Ir ratio. These fractionations are in stark contrast to the case of Allende coarse-grained inclusions in which these elements are nearly always in cosmic proportion to one another [4]. The low volatile content of BB-3 is noteworthy (< 17 ppb Au, 55 ppm Mn, 5.4 ppm Co). Its Na content is < 240 ppm, the lowest so far seen in any refractory inclusion. It has thus undergone no

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detectable low-temperature alteration, either in the nebula or in the parent body, contrary to what would be expected from the massive hydrothermal alteration envisioned by McSween [8] to have occurred in the parent body of C2 chondrites.

RNAA determinations of REE in M-11 confirm the inference [2] that it has a Group II REE pattern. Light REE, Tb, Dy, Tm, Yb and Lu are enriched relative to Cl's by factors of 50, 30, 25, 35, 18 and 8, resp. Eu is depleted relative to light REE by a factor of 5 and Gd, slightly more enriched than Tb in normal Group II patterns, is almost as depleted as Eu. Because Gd is the only REE determined *via* a p-process isotope, ^{152}Gd , we suspected that its unusually low abundance was due to a depletion of p-process isotopes in M-11. Uncertainty in the determination of Gd *via* ^{158}Gd , an r-, s-process isotope, is so great that the case for an isotope anomaly is inconclusive. But, because determinations of Yb *via* its p-process isotope, ^{168}Yb , and an r-, s-process isotope, ^{174}Yb , are in precise agreement with one another, we conclude that the Gd anomaly is probably a chemical effect. We reported similar Gd anomalies in the FUN inclusion HAL [9] by INAA and we have now confirmed their existence therein by RNAA. Davis and Grossman [10] claimed that Group II inclusions contain two REE-bearing components: one depleted in heavy REE and other highly refractory elements (Hf, Ir) by solid-gas fractionation and the other uniformly enriched in all refractories. The low Tb/Sm ratio suggests that most of the Lu and other highly refractory elements are depleted to vanishingly small concentrations in the fractionated component in M-11. The relatively high Lu/Sm ratio implies that nearly all of the Lu, Hf and Ir are due to the flat component. The enigma of the high siderophiles in M-11 is thus solved, as Ir should be enriched to the same degree as Lu and Hf, as observed [2]. Another possibility is that one of the inclusions comprising M-11 has a normal Group II pattern and low Ir and the other is a normal Group I inclusion with high siderophiles. Again, Na (545 ppm) and Au (27 ppb) are very low compared to most Allende coarse-grained inclusions. Perhaps this is a general feature of refractory inclusions in Murchison.

IMMA of two areas of the pure hibonite grain DJ-1 ($^{27}\text{Al}/^{24}\text{Mg}=120$ and 190, resp.) gave Mg isotopic compositions indistinguishable from the terrestrial value with no evidence for either excess ^{26}Mg or mass-fractionated Mg, as was also the case for the pure hibonite grain, MH88, studied in [6]. $^{26}\text{Al}/^{27}\text{Al}$ was $< 3 \times 10^{-6}$ when DJ-1 formed. In contrast, three melilite areas with distinctly different $^{27}\text{Al}/^{24}\text{Mg}$ in MUM-1 show ^{26}Mg excesses linearly correlated with this ratio. With isotopic data from a spinel in this inclusion, they give a four point Al-Mg isochron (Table 1) with a slope, $(^{26}\text{Al}/^{27}\text{Al})_0 = (4.5 \pm 0.6) \times 10^{-5}$. These data are the first clear evidence of radiogenic ^{26}Mg in a Murchison inclusion. This slope is identical to that of the standard isochron found in several Allende Type B inclusions [11,12,13], suggesting that some Murchison refractory inclusions are contemporaneous with Allende inclusions. The data points plot very close to the isochron, giving no evidence that Mg isotopes were disturbed during the alteration of MUM-1 described in [7]. This is in contrast to the Mg isotopic behavior during alteration that was documented in some Allende inclusions [14,15]. If the absence of excess ^{26}Mg in DJ-1 is due to late formation, an interval of at least 4 My must separate its formation time from that of MUM-1.

We have found no evidence in the samples studied here for trace element contamination introduced by our recovery procedures described in [7], although removal of soluble constituents cannot be ruled out. Refractory inclusions from Murchison often appear to be higher-temperature condensates than their counterparts in Allende and also seem to be less altered by later processes than the latter.

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Table 1.

<u>Sample</u>		<u>$\delta^{26}\text{Mg}$ (‰)</u>	<u>$^{27}\text{Al}/^{24}\text{Mg}$</u>
DJ-1	Hibonite #1	1±2	120±10
	Hibonite #2	1±1	190±10
MUM-1	Spinel	-1±1	2
	Melilite #1	18±2	54±5
	Melilite #2	14±3	44±5
	Melilite #3	2±1	14±2

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