CHEMICAL STUDIES OF CONDENSATES IN THE MURCHISON TYPE 2 CARBONACEOUS CHONDRITE, L. Grossman*, A.M. Davis*, E. Olsen** and P.M. Santoliquido*, *Dept. of Geophysical Sciences, University of Chicago, Chicago, Il. 60637. **Dept. of Geology, Field Museum of Natural History, Chicago, Il. 60605.

The Murchison Type 2 carbonaceous chondrite consists of a wide range of mineralogically diverse, submillimeter inclusions embedded in a very fine-grained matrix of hydrated layer-lattice silicates. Detailed petrographic descriptions of many of these inclusions were reported in (1). Euhedral, forsterite-rich olivine crystals are commonly found as whole individuals or fragments thereof scattered throughout the matrix. They contain tiny inclusions of Ca-, Al-rich glass and nickel-iron grains with unusually high Cr and P contents. Polycrystalline aggregates of such olivine grains are the most common type of inclusion in Murchison. No intervening glass cements the crystals together in these, but occasional fibers of hydrated silicates are found adhering to the olivine crystals. Ca-, Al-rich inclusions are extremely rare. They possess cores of hibonite, mantles of intergrown perovskite, spinel and diopside and outer zones of pure diopside. Melilite is conspicuously absent from these, in contrast to their counterparts in the Allende C3 chondrite. Chondrules are rare. In narrow bands surrounding many of the inclusions, the matrix is unusually lustrous, dark and free of coarse grains. We report here the first results of a trace element study of separated petrographic constituents from Murchison aimed at elucidating the condensation history of components of C2 chondrites. All data were obtained by INAA.

The texture and mineralogy of Ca-, Al-rich inclusions in Murchison (1) suggest that they could be refractory condensates from the solar nebula. The abundance of hibonite and absence of gehlenite imply that hibonite, rather than corundum, was the first Al-bearing condensate as was suggested in (2) and that this hibonite was unable to react with the gas at 1600°K to form melilite. This could indicate that cooling rates were more rapid in the region of the nebula where the Murchison inclusions formed than where the coarse-grained Allende inclusions did. The Ca-, Al-rich inclusions in Murchison seem to have stopped equilibrating with the nebula at a much higher temperature than the coarse-grained Allende inclusions and thus represent the highest-temperature condensates we have seen to date. It was of obvious importance to analyse such material in order to see how the trace element abundance pattern differs from that of the lower-temperature Allende inclusions. Consequently, two inclusions with deep-blue hibonite cores were extracted and mixed together to give a total sample size of 106 micrograms. In Figure 1, the results show that all 17 refractory elements determined are strongly enriched in the hibonite-bearing inclusions relative to their abundances in Cl chondrites, as is expected from theory (3). Like coarse-grained inclusions in Allende, the enrichment in refractories applies both to lithophile and to siderophile elements. This is quite distinct from the fine-grained Allende inclusions which are enriched in refractory lithophiles but strongly depleted in refractory siderophiles(4). Another distinction is that contents of the more volatile elements Fe, Mn and Na are 3-50 times lower in the hibonite than in fine-grained inclusions. Some similarities to fine-grained Allende inclusions are also evident. Figure 2 compares the REE pattern of the hibonite-bearing inclusions to the typical REE pattern of Martin and Mason's (5) Type II fine-grained inclusions in Allende.

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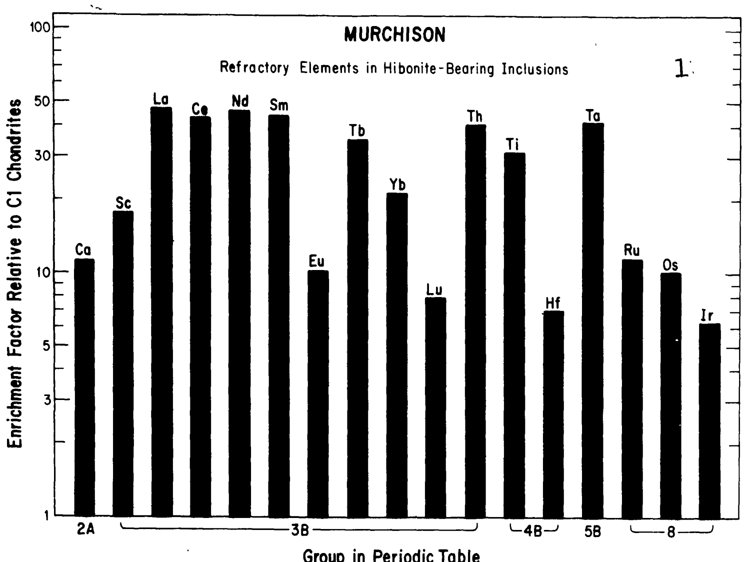

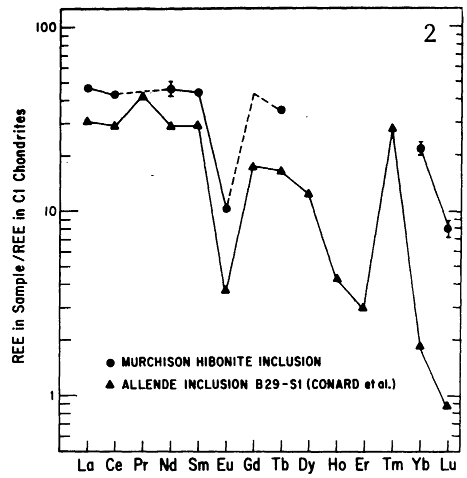

The 40-50 times enrichment in light REE, lower enrichment in Tb, sharp negative Eu anomaly and steep drop from Yb to Lu in the hibonite sample are all very similar to their counterparts in the REE pattern of the fine-grained inclusion and, together, match no other type of REE pattern known from condensate inclusions. As has been reported previously for fine-grained inclusions (4), Ta is enriched by a similar factor to the light REE while Ca and Sc are significantly less enriched than these. The discovery of this highly fractionated refractory lithophile enrichment pattern so typical of Allende fine-grained inclusions in these hibonite-and perovskite-rich ultra-high-temperature condensates in Murchison strongly suggests that their REE patterns do not originate by condensation of the residue left after prior condensation of the more refractory REE in perovskite or any other phase, as has been suggested in (6) and (4). They may be due instead to the way in which hibonite, perovskite or some trace phase in the inclusions partitions REE during condensation or perhaps to non-equilibrium condensation during rapid cooling.

We analysed a large (1.54mgm) metal bead which was found embedded in the hydrous silicate matrix. It contains 92.2% Fe, 6.80% Ni, 2900 ppm Co and 5471 ppm Cr (sum=99.84%). These are within their respective concentration ranges in the tiny metal inclusions inside the olivine crystals in C2 chondrites, as measured by electron microprobe in (7) and (8), suggesting that this metal bead belongs to the same population of objects. As suggested in (8), the concentrations of these elements are consistent with condensation of the metal grains in the solar nebula and their failure to equilibrate with the vapor below about 1400^{o}K at 10^{-3} atm. total pressure. As shown in Figure 3, the refractory siderophiles Os and Ir are enriched in the metal bead relative to Fe compared to their cosmic ratios to Fe. Because these elements condense totally before Fe (9), their enrichment also indicates cessation of equilibrium somewhere above the temperature of complete condensation of Fe, probably about 1400^{o}K. In accordance with such an equilibration temperature, the elements Cu, As, Ga and Sb, which condense between 1250 and 1000^{o}K, are depleted by between one and two orders of magnitude relative to Fe compared to the solar abundances and

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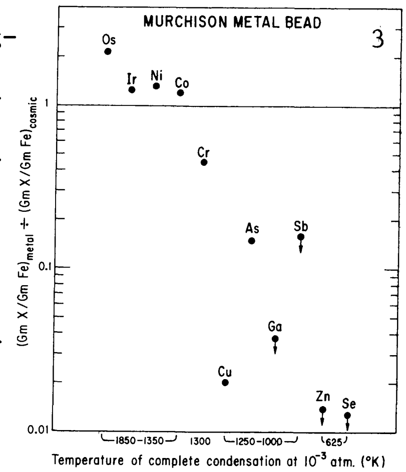
the elements Zn and Se, which condense totally with troilite at 625°K, are depleted by two orders of magnitude or more. The trace element composition of the metal bead thus confirms the suggestion that metal grains inside the olivine crystals are direct condensates from the solar nebula as originally proposed in (7) and (8) based on their major and minor element contents. This implies, in turn, that the olivines which enclose the metal grains are also condensates and that the sequence of condensation was metal first, then forsterite, in the region of the nebula where these components of Murchison formed.



Two collections of isolated olivine crystals were made and analysed separately. Sc and Eu are more enriched in both samples relative to Cl chondrites than are La and Sm. If these elements are present mostly in the tiny glass inclusions rather than in the structure of the olivine crystals, then the glasses did not form by melting of the hibonite-rich inclusions, but represent some other type of refractory condensate. Ir contents of the olivines suggest that they contain, at most, an average of 1-2 wt % metal inclusions having the composition of the metal bead. Olivines were also collected from a total of 16 olivine aggregates and analysed as a single sample. Refractories are higher by factors of 5 to 10 than in isolated olivines. Here, Sc is again more enriched relative to Cl chondrites than La and Sm, but Eu is less enriched. This indicates that a different refractory component may be present in the glass inclusions in the aggregated olivines than in the isolated olivines.

In an attempt to analyse uncontaminated matrix, we determined the concentrations of 23 elements in a 0.59 mgm sample of the lustrous black matrix shell surrounding an olivine aggregate. It is remarkably similar in composition to the bulk meteorite except for its higher contents of Zn (259 vs 165 ppm), Br (3.3 vs 1.7ppm) and Sb(173 vs 107ppb). The enhancement of the matrix in these volatile elements relative to the bulk meteorite is predicted by models which picture C2 chondrites as mixtures of low-temperature, volatile-rich matrix with high-temperature condensates and chondrules (7,10).

References: 1. Fuchs, L.H., et al. (1973). Smith. Cont. Earth Sci. 10. 2. Grossman, L. and Clark, S.P. Jr. (1973). GCA 37, 635-649. 3. Grossman, L. (1973). GCA 37, 1119-1140. 4. Grossman, L., and Ganapathy, R. (1976). GCA 40, 967-977. 5. Martin, P.M. and Mason, B. (1974). Nature 249, 333-334. 6. Boynton, W.V. (1975). GCA 39, 569-584. 7. Olsen, E., et al. (1973). GCA 37, 2037-2042. 8. Grossman, L. and Olsen, E. (1974). GCA 38, 173-187. 9. Palme, H. and Wlotzka, F. (1976). EPSL 33, 45-60. 10. Larimer, J.W. and Anders, E. (1967). GCA 31, 1239-1270.