A SIMS STUDY OF SOME ALLENDE CHONDRULES: SUPPORT FOR THE NEW CHONDRULE MODEL; G. Kurat[1], F. Brandstätter[1], E. Zinner[2], H. Palme[3] and B. Spettel[3], [1]Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria, [2]McDonnell Center for the Space Sciences and Physics Department, Washington University, St.Louis, MO 63130, USA, [3]Max-Planck-Institut für Chemie, D-6500 Mainz, Germany

Bulk major and trace element contents of chondrules strongly suggest that chondrules formed from primitive components, presumably early condensates of the Solar nebula (cf [1] and refs. therein). In particular, the refractory lithophile elements (RLE), although present in highly variable amounts, are usually unfractionated, clearly indicating that the original components did not experience any geochemical fractionation. This in turn strongly suggests that the RLE (and maybe also some other elements) were collected in a major, or perhaps the main mineral phase. This idea led to a new model for chondrule formation [2-4] in which chondrule precursors are formed by aggregation of condensate olivine. Because this olivine is assumed to be the major (and probably only) phase to condense from the Solar nebula gas, it became the host for all lithophile elements oversaturated in the gas, in particular, all RLEs. SIMS analyses of such primitive olivines [5] from proto-chondrules in All-AF, a primitive rock fragment in Allende [3], impressively demonstrated the validity of this assumption: these olivines carry the bulk amount of all lithophile trace elements in unfractionated relative abundances. Chondrules can be derived from such aggregates of primitive condensates by subsequent sintering and/or partial to total melting. During this subsequent event, the primitive and badly crystallized olivines are expected to recrystallize and expel their trace elements which are present at levels up to $\approx 10^5$ times the amounts predicted (and allowed) by olivine-liquid distribution coefficients [e.g.6]. Redistribution of RLE must have taken place between olivines and the newly forming chondrule matrix (or partial melt) and will depend on several factors such as incompatibility and mobility (dependent on ionic charge and temperature) of a given element and on the environment in which such thermal treatment takes place. In case a partial melt forms, the trace elements will attempt to partition into that melt according to partition coefficients and mobility. Since different individual chondrules are likely to have experienced different thermal conditions (e.g., intensity and duration), we can expect to find olivines of different chondrules in different stages of the attempted equilibration with the partial melt.

In order to test this model we analyzed olivine and co-existing matrices in chondrules from Allende by ion microprobe mass spectrometry following the procedures of [7]. Samples were selected from a collection of chondrules previously analyzed by INAA and EMP [1,8] according to the following criteria: 1) Olivines must be

Table: Major and trace element contents (ppm) of olivine and matrix (SIMS) and bulk chondrules (INAA) from Allende.

	ACH-10 Bulk	Matrix	Olivine	ACK-1 Bulk	Matrix	Olivine
Na	2180	4957	374	10290	9095	193
Al		112348	1486		132700	2208
K	190	210	91	70	561	12.84
Ca	28200	114870	2451	20000	109620	3704
Sc	22.5	51.2	7.54	22.1	26.6	17.6
Ti	2200	9130	239	10000	5840	820
Mn	397	163	100	912	514	66
Fe	37500	3728	5716	68700	15831	1286
Sr	30	86	1.07	50	103.2	0.158
Y		24.7	0.199		14.2	0.576
Zr		81	0.187		67.3	0.62
Nb		4.2	0.031		3.5	0.0118
La	0.75	2.8	0.0078	0.82	2.8	0.0047
Ce	2.0	7.7	0.019	2.1	7.3	0.0156
Nd	1.4	6.2	0.0098	1.7	4.9	0.0118
Sm	0.463	2.4	0.0041	0.52	1.28	0.007
Eu	0.159	0.55	0.0061	0.2	0.55	0.0015
Tb	0.12	0.6	0.0017	0.14	0.40	0.006
Dy	1.01	4.8	0.022	0.99	2.6	0.060
Yb	0.49	2.4	0.060	0.64	1.71	0.176
Lu	0.086	0.40	0.0100	0.095	0.19	0.037
Hf	0.44	1.1	0.009	0.38	0.9	0.024

large enough for SIMS (≈ >40μm), and 2) olivines should have very low Fe contents and high Al, Ca, and Ti contents in order to guarantee primitivity.

Trace element data for bulk, matrix, and olivine for two chondrules are given in the Table. ACK-1 is a porphyritic olivine (mosaic-type sinter) chondrule with very few opaque phases. Its olivine composition ranges from Fa ≈0.2 (center) to Fa 13 with the low-Fe portion containing 0.09wt.% TiO_2, 0.42% Al_2O_3, and 0.59% CaO. ACH-10 is a porphyritic olivine-pyroxene chondrule, also very poor in opaque phases. Its olivine, however, is richer in FeO than that of ACK-1 (Fa≈0.5%) and somewhat lower in minor elements (Table). Bulk, matrix, and olivine trace elements data given in Fig. 1 are normalized to CI [9]. The bulk composition, typical for most Allende chondrules, shows a flat RLE pattern at about 3×CI. The matrix has a similar pattern at a higher level, which is approximately the same for all chondrules of this study. Exceptions are only Sc and V, which are retained in the olivine at high abundances. The olivine pattern approximately reflects the olivine-liquid partition coefficients but only in an inconsequent way. Sc, V, and most of the highly incompatible elements (light rare earths, Nb, Zr, Hf) are overabundant [6,10] and thus demonstrate that they could not have crystallized from the chondrule melt.

As predicted, there is a range in trace element contents of olivines from different chondrules. Two of them are compared to olivine from All-AF [5] and to an isolated olivine (iso-ol) from Allende [11] in Fig. 2. All olivine compositions can be derived from the All-AF olivine by (a) tempering and recrystallization of an All-AF-like olivine in the gas phase (no liquid is competing for the trace elements); this could result in the pattern of the isolated olivine, or (b) tempering and recrystallization of olivine in contact with contemporaneously forming partial melt; this should result in the patterns observed for the olivines from chondrules. The steepness of the REE pattern and the enrichments of the heavy REE will be governed by the temperature and duration of the chondrule-forming heating event. In no case is equilibrium reached between matrix and olivine. Partition coefficients predict much lower REE [6] and Sc, V [10] contents. However, our data also clearly show that isolated olivines in CCs do not originate from chondrules as suggested by [12]. Rather it appears that isolated olivines and chondrule olivines have a similar primitive precursor [2].

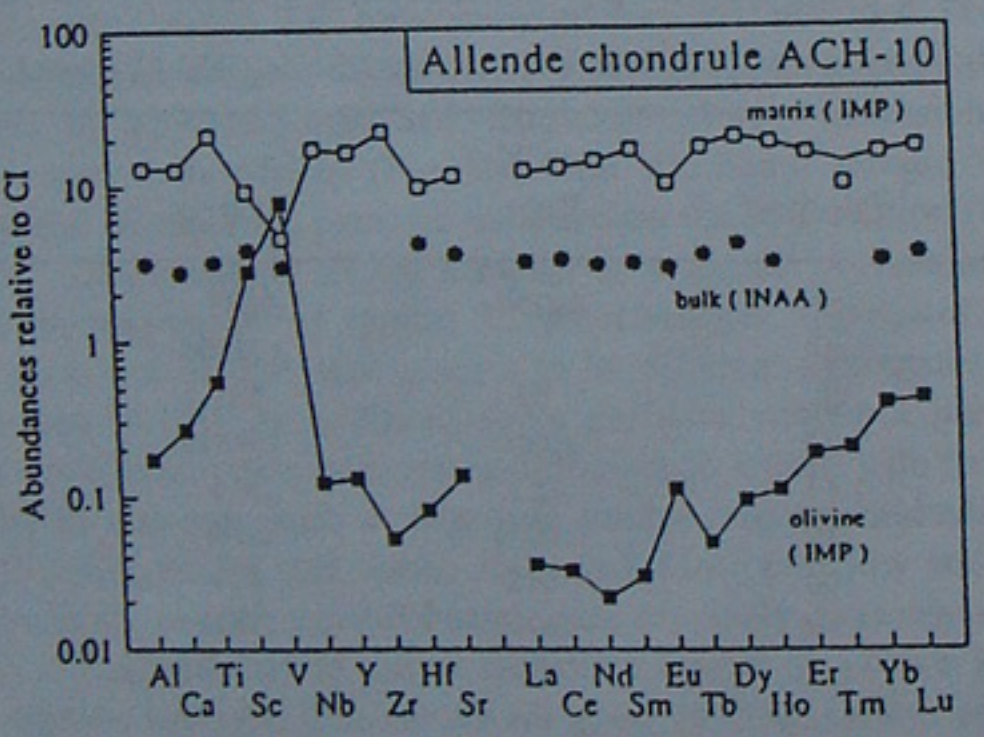

Fig. 1: CI-normalized [9] trace element abundances in chondrule ACH-10 bulk, matrix, and olivine (Table).

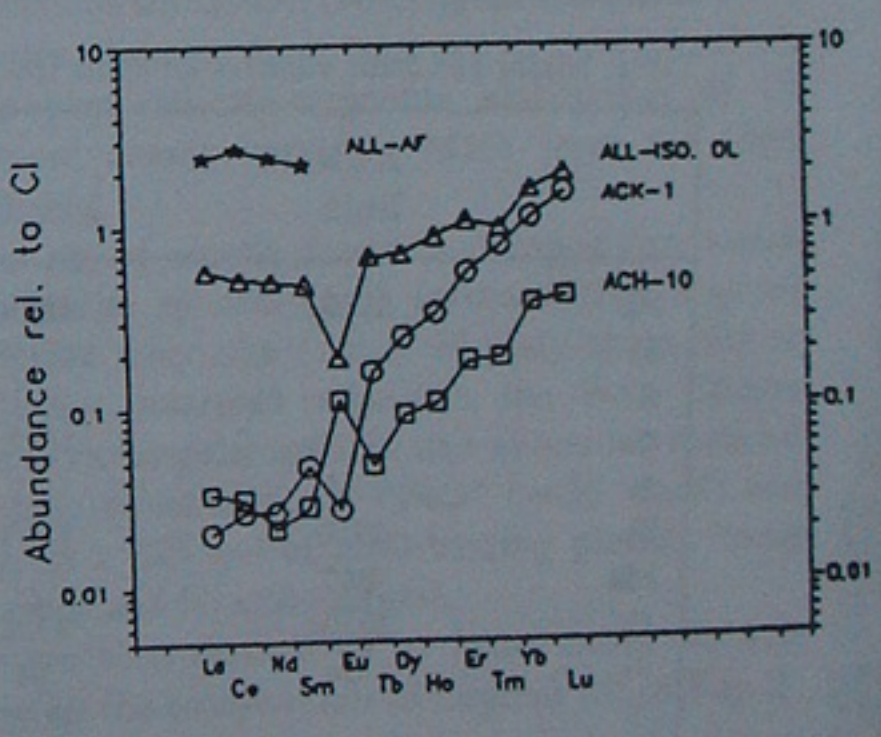

Fig. 2: CI-normalized [9] REE abundances in olivine from All-AF [5] (pattern is likely to be flat but HREE were not determined), an isolated olivine from Allende (All-iso-ol [11]) and olivines from chondrules ACK-1 and ACH-10 (Table).

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