ALLENDE CHONDRULES: DISTILLATIONS, CONDENSATIONS,AND METASOMATISMS.

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Six chondrules, perfectly round to oval, were selected and bulk analyzed by INAA for a variety of mostly trace elements. Subsequently thin sections were prepared and bulk major element contents and phase compositions were determined by electron microprobe techniques. Selected results are given in the Table. They can be summarized as follows: (A) The refractory lithophile elements (RLEs) are generally enriched between 2.5x and 8.5x CI and grossly unfractionated - in accordance with previous results (1). A few anomalies, however, are common: (a) two chondrules have negative Ca anomalies (both PO-mosaic) (b) one chondrule (poikilitic px-ol-an) has large negative anomalies in the abundances of Lu and Sc as compared to other RLEs. (B) The moderately volatile lithophile elements Cr and Mn are generally depleted as compared to the RLEs. The degree of depletion is lowest for the two RP chondrules, higher and very similar for the remaining four chondrules. Cr is always less depleted than Mn, a feature also common among CAI's and amoeboid olivine aggregates (2,3). (C) The volatile lithophile elements Na, K, Cl, and Br show rather complex patterns. All chondrules have positive alkali anomalies of different magnitude and type. The two RP chondrules show the smallest anomaly with Na < CI < K. All other have (Na,K) > CI. Cl and Br abundances appear to be linked to the alkali fractionation pattern: For chondrules with Na/K > CI Cl and Br abundances are > (Na,K) (All-CK1, All-CK2). Chondrules with Na/K ≤ CI have Cl and Br abundances < (Na,K). With decreasing Na/K the halogen abundances fall. Interestingly, these relationships also hold for most CAI's (2) and also for Qingzhen (E3) chondrules(4). (D) The siderophile element abundances are generally low and show three principal patterns: (a) Both RP chondrules have very low Ir contents and increasing abundances with increasing volatility. On top of that pattern they show a strong positive Fe anomaly. (b) Chondrules All-CK1 and All-CK3 have roughly chondritic relative abundances of Ir, Ni, Co, and Fe. (c) Chondrules All-CK2 and All-CK4 show chondritic relative abundances for Ni, Co, and Fe, and very strong positive Ir anomalies. The Ir abundances are > CI but are always lower than the RLEs, a pattern similar to patterns commonly observed in CAI's (2).

Interpretations: The general enrichments of RLEs as compared to CI (and Allende bulk)composition together with the depletion of the moderately volatile elements Cr and Mn (in a regular manner) strongly suggest that vapor fractionation took part in chondrule formation. The grossly unfractionated RLE patterns observed could indicate destillation processes, similar to what has been suggested for CAI's (5). An exception is All-CK3 which is depleted in the most refractory RLEs Lu and Sc (relative to the others), a pattern which indicates involvement of vapor-solid fractionation (and condensation from that vapor). The relatively high contents of the volatile elements Na and K are - at first sight - suggestive of metasomatic alteration. Careful petrological investigations, however, reveal that, although most chondrules display some alterations, not all of them do and if, the volumes affected are much too small to account for the substantial enrichments observed. In fact, Na and K are always present in substantial amounts in the (melt-derived) matrices. In addition, All-CK2 shows no evidence for any alteration (except for a tiny pentlandite near the surface). It appears, that Na and K must have been

present during the (partial) melting event which formed the chondrules. Since alkali loss is almost complete within a few seconds during melting (6), melting must have taken place within a dense, alkali-rich atmosphere, or the alkalis were stabilized by more refractory phases. The correlation between Na/K fractionation and the abundances of Cl and Br could indicate the involvement of complex sulfides, similar to what has been suggested for Chainpur chondrules (7). Recent data on Qingzhen chondrules (4) tend to support this view. Sampling fractionations apparently are minor in Allende chondrules, indicating small grain-sizes of the precursor matter. The small negative Ca anomalies observed in two chondrules could indicate such a process. The siderophile element patterns provide some additional clues: the increase of abundances with volatility in the RP chondrules probably indicates a condensation process. The strong positive Fe anomaly present in these chondrules cannot be accounted for by metasomatic processes alone. In fact, the px compositions in these chondrules are rather uniform and could represent the primary composition. That is fairly FeO-rich, an indication for elevated fO2. The grossly flat siderophile element patterns of All-CK1 and All-CK3 apparently just indicate metal-silicate fractionation with minor (vapor) fractionation of Au. In contrast, chondrules All-CK2 and All-CK4 reflect minor metal-silicate fractionation (high fO2) but strong vapor fractionation which resulted in Ir abundances comparable to RLE abundances but low moderately volatile siderophile element contents. The positive Au-As anomaly observed in All-CK4 (and maybe also All-CK3) could possibly be the result of metasomatism which is also evident from migrations of O, S, Fe-Ni-S, FeO, and Na2O-K2O-Cl.

References: (1) Osborn T.W.(1971) Thesis, Oregon State Univ. (2) CAI data collection MPI Mainz. (3) Grossman L., R.Ganapathy, R.L.Method, and A.M.Davis (1979) Geochim.Cosmochim.Acta 43, 817-829. (4) Grossman J.N., A.E.Rubin, E.R. Rambaldi, R.S.Rajan, and J.T.Wasson (1984) preprint. (5) Kurat G.(1970) Earth Planet.Sci.Lett.9, 225-231. (6) Housley R.M. and E.H.Cirlin (1984) Lunar Planet.Sci.XV, 381-382. (7) Kurat G., E.Pernicka, and I.Herrwerth (1983) Earth Planet.Sci.Lett.68, 43-56.

Table: CI normalized selected element contents, masses and mineral chemical data for chondrules from Allende.

Chondr.	All-SHE	All-A38	All-CK1	All-CK3	All-CK2	All-CK4
Text.	RP	RP	POmos	Poik	PO	POmos
Lu	3.0	2.4	3.8	1.3	7.2	3.7
Sc	3.2	2.5	3.7	1.6	8.4	3.4
Sm	3.2	2.5	3.4	3.4	7.7	3.3
Cr	1.7	1.8	1.1	1.1	1.0	1.0
Mn	0.89	1.04	0.50	0.44	0.44	0.47
Na	0.75	0.89	2.1	2.7	2.5	1.7
K	1.4	1.5	1.4	2.7	1.1	2.0
Cl	0.31	0.52	2.5	1.5	3.7	0.44
Ir	0.023	0.014	0.32	0.33	2.5	2.2
Ni	0.029	0.016	0.40	0.24	0.14	0.36
Co	0.039	0.030	0.42	0.24	0.14	0.35
Fe	0.24	0.27	0.36	0.29	0.14	0.36
Au	0.077	0.044	0.20	0.54	0.17	0.70
Mass,mg	800	236.3	24.5	9.32	16.1	3.86
fa	(22.7)	-	0.3	1.2	0.3	0.4
fs	5.5	5.2	1.1	1.2	-	-
Fe/Mn_{Ol}	126	-	13.0	15.3	10.4	-
Fe/Mn_{Px}	13.9	13.8	4.8	8.5	2.6	-