

CONDENSATION AND THE MINERAL ASSEMBLAGES OF CHONDRULE PRECURSORS Roger H. Hewins, Laboratoire de Minéralogie, Muséum National d'Histoire Naturelle, 61 rue de Buffon, 75005 Paris, France

Introduction The precursors of chondrules were probably assembled from condensate minerals, since the presence of refractory oxide (SHIB) and silicate (CAI) inclusions, forsterite, enstatite and ferroan olivine as isolated fractions within primitive meteorites seems impossible to explain without condensation. The minerals in the precursors can be determined by matching bulk compositions with minerals in a MIXING program, assuming that volatiles were not lost during melting and that the minerals are those abundantly represented in condensation sequences and in unequilibrated chondrites. Although it is widely agreed that chondrules were formed by melting of minerals, previous studies of their precursors (e.g. 1,2) were aimed at identifying chemical components (correlated elements) rather than specific phases.

Volatile Loss? Type II (i.e. ferroan) PO (porphyritic olivine) chondrules in Semarkona (3) have an Na/Al ratio of 1.01 ± 0.06 (s.d.) and very low K abundances. This requires that their precursors incorporated a NaAl mineral, which from petrologic considerations must be albite, and that no Na was subsequently lost during melting. Type I (magnesian) chondrules have Na/Al much less than 1. The initial temperatures of Type I and II chondrules in Semarkona overlap substantially (4) and there are no differences in thermal history to indicate volatile loss as the cause of the low Na/Al. We therefore explore the possibility that chondrule compositions, including Na concentrations, are entirely controlled by precursor assemblages.

Precursor Phases Forsterite and enstatite are prominent in condensation sequences and as relict grains, and are therefore the chief contenders for chondrule precursors. Since Semarkona Type II PO chondrules (3) have Na/Al 1:1, their precursors contained no Al phase other than albite and Ca must have been present as an Al-free mineral: inspection of condensation sequences (5,6) reveals diopside as the only logical candidate. Most chondrule suites (including some other Type II chondrules) have Na/Al less than 1, requiring additional Al phase(s), if Na and Ca remain as albite and diopside. Spinel is the Al phase which accompanies forsterite in the classical condensation sequence (5), although Al silicates may also be considered.

Mixing Calculations: Caveat It is impossible to obtain unique solutions to mixing calculations, particularly for minor elements as most minerals are solid solutions. Natural forsterite and enstatite containing minor elements (7-9) were used, plus fayalite (Fa100 or Allende matrix olivine composition), pure albite, orthoclase, tephroite, perovskite, phosphate and iron if needed. Although solutions vary depending on the choice of carrier phases, the calculated abundances of the major minerals do not change significantly. Ca-Al minerals, including melilite and anorthite assemblages, are mathematically comparable to spinel+diopside, given major adjustments to the quantities of Mg-Si minerals (Fo,En), and such phases also occur in condensation sequences. However, simpler more systematic solutions to mixing calculations were obtained using spinel+diopside rather than melilite or anorthite assemblages.

Results Semarkona Type II (3) precursors were essentially Fo-En-Di-Ab-Fa, always with abundant Ab, En and zero spinel (see table). Other Type II chondrules, e.g. CV, had very similar Ab, similar or higher Di, up to 2% Sp, and always little En. Type I precursors are matched as Sp-Fo-En-Di-Ab-Fa aggregates, always with low Fa, generally but not always low Ab, and sometimes low Fo.

CHONDRULE PRECURSORS: Hewins R.H.

The Type I chondrule precursors had more refractory phase (Sp) than Type II, always less Fa (by definition) but not always less Ab. The CV Type II chondrule precursors had a little spinel and sometimes much less Ab than Semarkona Type II, but similar fayalite. The En-Fo differences confirm that in carbonaceous chondrites, Type I and II chondrules are essentially Fo-En (Type IA being Fo-rich and Type IB being En-rich) and Fo-Fa mixtures respectively, but UOC Type II chondrules are Fo-En-Fa mixtures.

Table: Percentages of Calculated Precursor Minerals of Chondrules*

Chondrite	Type	Ref.	Sp	Di	Fo+En	Ab	Fa	Fo	En
Efremovka	I	13	3-16	5-22	77-86	1-6	1-5	0-58	20-86
Semarkona	I	14	1-8	8-23	65-85	1-6;17	0-3	28-74	0-43
all CV	II	13	0-3	5-12	26-65	9-21	15-37	26-65	0-6
Semarkona	II	3	0	1-5	61-64	10-17	13-23	39-52	12-24

(* + up to 2% tephroite, orthoclase, perovskite and phosphate, and up to 5% Fe.)

Condensation and Assembly The dominant Type I chondrule precursor phases formed at 1500-1300K in the equilibrium condensation sequence (5), but minor Ab and Fa were added. Type II precursors are similar except that spinel is low (CV, CO) or absent (Semarkona of (3)), Ab is generally abundant, and Fa is abundant by definition. As it resulted in different kinds of chondrule and CAI precursors, condensation was clearly fractional not equilibrium. Apparently different pathways in condensation (e.g. Fo-En in CC Type I precursors, and Fo-Fa in CC Type II precursors) may be due not to oxygen fugacity differences (10) but to kinetic factors: rapid cooling might inhibit the reaction of Fo with the gas to form En and allow the precipitation of Fa after supersaturation. One can then regard Type IB precursors not principally as having formed at higher temperatures but as having experienced more reaction with gas (as opposed to precipitation), as compared to Type II.

In some UOC, e.g. ALH 77015 and Manych (11-12), there are ferroan, Na-poor chondrules: fayalite was added to the precursors but albite was largely bypassed. It is not required that this albite failed to condense. Many such chondrules contain relict grains of ferroan olivine (11), so their compositions may be controlled by different assembly rather than condensation pathways i.e. collision and mixing of Type I chondrule droplets with late low-temperature condensate grains.

References

- (1) Grossman J.N. and Wasson J.T. (1983) *Geochim. Cosmochim. Acta* 47, 759-771.
- (2) Rubin A.E. and Wasson J.T. (1988) *Geochim. et Cosmochim. Acta* 52, 425-432.
- (3) Jones R.H. (1990) *Geochim. Cosmochim. Acta* 54, 1785-1802. (4) Hewins R.H. (1991) *Geochim. Cosmochim. Acta* in press. (5) Grossman L. (1977) in *Comets, Asteroids, Meteorites*, 507-516, ed. A.H. Delsemme, U. Toledo. (6) Wood J.A. and Hashimoto A. (1988) *Lunar Planet. Sci.* XX, 1215-1216. (7) Steele I (1986) *Geochim. Cosmochim. Acta* 50, 1379-1395. (8) Wark D.A. et al. (1987) *Geochim. Cosmochim. Acta* 51, 607-622. (9) Kracher A. et al. (1984) *Proc. Lunar Planet. Sci. Conf.* 14th, B559-566. (10) Hewins R.H. (1989) *Proc. NIPR Symp. Antarctic Meteorites* 2, 200-220. (11) Nagahara H. (1981) *Mem. NIPR Spec. Issue* 20, 145-160 & (1983) *In Chondrules and their Origins*, 211-222, ed. E.A. King, LPI Houston. (12) Dodd R.T. (1978a,b) *Earth Planet. Sci. Lett.* 39, 52-66 & 40, 71-82. (13) McSween H.Y. Jr. (1977) *Harvard-Smithsonian Cent. Astrophys. Rept.* (14) Jones R.H. (1990) *Geochim. Cosmochim. Acta* 54, 1785-1802.