DUSTY OLIVINES IN THE VIGARANO (CV3) CHONDRITE: EVIDENCE FOR AN UBIQUITOUS REDUCTION PROCESS. Alfred Kracher, Edward R.D. Scott, Klaus Keil, Institute of Meteoritics, Department of Geology, University of New Mexico, Albuquerque, NM 87131.

1. Introduction: Olivines with finely dispersed Ni-poor metal have been described from chondrules and as isolated grains in ordinary chondrites [1-3], but have not previously been found in carbonaceous chondrites. These grains have been interpreted as relicts of some kind of precursor rock, which were incorporated as solid grains in the still liquid chondrule. Presence of reducing agents inside the original olivine grain has been postulated [3], but similar textures can be experimentally reproduced by heating of Fe-bearing olivine in a reducing atmosphere [4].

Since there is other evidence that reduction accompanied the formation of certain types of chondrules, the formation of dusty olivine may be a special case of this widespread reduction process.

2. "Dusty olivines" in Vigarano: We have found three dusty olivine grains in a thin section of Vigarano (CV3). They closely resemble similar occurrences in ordinary chondrites [3] in both textural and chemical properties, and appear to have the same origin. Two of the grains occur in chondrules, the third is a large olivine fragment/aggregate, probably from a chondrule, too.

(a) Chondrule X1 is a well-rounded droplet, with idiomorphic olivines (Fa=1.8±0.6) embedded in brownish, Ca-Al-rich glass, and some tangentially aligned, twinned low-Ca pyroxene around the edges (Fig.1). One olivine grain (Fig.3) has a dusty core containing very fine (<0.5 μm) metal grains, aligned along crystallographic planes. Only the clear rim could be analyzed by microprobe; it is higher in FeO (3.4%) and Cr_2O_3 (0.29%), and considerably lower in CaO (≤0.03%) than other olivines (1.78% FeO; 0.19% Cr_2O_3; 0.17% CaO). Aside from the unusual dusty grain, this kind of porphyritic olivine (±pyroxene) chondrule (PO) is common in CV and ordinary chondrites.

(b) Chondrule X3 consists of grains of olivine and pyroxene of various sizes with little mesostasis (Fig.2). One large pyroxene poikilitically enclosing olivine and one rounded olivine grain with an annular dusty region (Fig.4) are particularly noteworthy. Most of the olivines are optically continuous, including the chadacrysts; a similar texture has been described from a chondrule in Kota-Kota (E4) [5]. The dusty grain consists of a clear core (Fa=7.1±0.3), a dusty mantle with small, aligned metal particles, and a clear double rim; the inner rim is outlined by metal blebs, the outer rim by magnetite. The average composition of the rim corresponds to Fa=4.9±1.2. Other olivine grains in the chondrule have Fa=7.1 ±0.7. Pyroxene, however, is more reduced (Fs=1.2±0.5), and the pyroxene oikocryst is in disequilibrium with the enclosed olivine, which has a central composition of Fa=6.5±0.6. Earlier descriptions of similar textures in chondrules from ordinary chondrites [3,6] also mentioned zoning of the chadacryst, but in our case the chadacryst is partially surrounded by small metal/sulfide grains, so that high apparent FeO contents at the olivine/pyroxene interface (up to Fa=16) cannot be attributed unequivocally to zoning.

A high-precision determination of MnO in olivines shows that MnO is lowest in the clear core of the annular grain (0.06 wt %), higher in the rim and in small olivines throughout the chondrule (0.12 ±0.02%), and highest in the chadacryst (0.15%). The Fe/Mn ratio in the center of dusty grain (120) is almost as low as in the opaque matrix coating the object (144), whereas it is ~42 in other olivines. The center of the dusty olivine is also unusual in its high Al_2O_3 (0.26%) and Cr_2O_3 (0.50%), the latter being typical of dusty grains in ordinary chondrites as well [3]. The clear rims, and most clear olivine grains seem to have lost most of their Cr, which presumably became incorporated in the metal. Although metal grains large enough to be analyzed by microprobe have insufficient Cr to account for all the Cr loss from olivine [3], we have found very small grains with Cr/Fe ratios of up to 0.13. We also found a SiO_2-rich phase, presumably glass (approximate composition: 61% SiO_2; 2% Al_2O_3; 8% FeO; 16% MgO; 12% CaO), associated with the dusty metal.

A trace across one of the small olivine grains along the surface of the chondrule (Fig.5) showed that FeO decreases towards the surface, and a zone of dusty metal (high Fe, Cr) separates the olivine from a thin pyroxene layer with lower FeO, also decreasing towards the surface. Another layer of Cr-rich metal is present just inside the opaque matrix coating the entire object.

(c) Olivine grain X2 is similar in appearance to the grain in X1, except that it is much larger (400x600 μm). It is lower in FeO (Fa=1.5±0.5), but higher in MnO (0.11%) and CaO (0.22%); Cr_2O_3 is similarly high (0.49%) as in the center of the dusty grain from X3. It appears to be an isolated olivine, with some pyroxene adhering to it, and surrounded by a rim of matrix material. It is most probably of igneous origin, and may represent a grazing cut through a chondrule or a chondrule fragment.

3. Discussion: Both chondrules pose problems to our understanding of chondrule formation. PO chondrules like X1 are, except for the dusty grain, very common. If dusty olivine grains represent solid precursor material which, in rare cases, was incorporated into liquid droplets parental to chondrules, we are faced with the problem why this event appears to have had no influence on the crystallization history and texture of the chondrule. This suggests that chondrules of this type always contained seeds of incompletely melted precursor material. Textural comparison with synthetic chondrules [7] leads to the same conclusion. The presence of relicts is only recognized in those rare cases when they were originally high in FeO, and precipitated dusty metal [3], or when they were unusually FeO-poor [8]. The survival of dusty grains may also be limited because metal may normally coalesce to larger beads. A survey of PO chondrules in Vigarano, Mokoia (CV3) and Murray (CM2) showed that many olivine crystals contain a small number of spherical metal blebs; a study of these is in progress.

Chondrule X3 suggests that the process which led to reduction of olivine was complex. Both olivine and pyroxene apparently crystallized from a melt, but the parent melts had different FeO contents. If there is any relationship between them, pyroxene crystallized after olivine (because of the poikilitic texture), following an intervening reduction event. Moreover, the concentration profile across the chondrule surface suggests that the whole chondrule was suspended in a reducing environment. These facts are most easily explained if during or after the initial crystallization of olivine the chondrule environment became more reducing, causing metal to precipitate inside the olivine while also lowering the FeO content of the residual melt (the metal from the latter process was presumably lost from the chondrule). This genetic history is somewhat similar to the proposed origin of igneous, Ca-Al-rich fragments in Lance [9]. If this model is correct, many of the dusty olivine grains may have crystallized and been reduced in situ. Therefore, dusty grains should not necessarily be regarded as relict grains.

4. Conclusions:

(a) Vigarano (CV) contains chondrules with dusty olivine grains, supporting a common origin for chondrules in all chondrite types [10].

(b) There is no need to invoke a reducing agent inside olivine grains, since dusty grains can be artificially produced without it [11].

(c) Although some dusty grains may be relicts [2,3], the reduction may in some (many?) cases have taken place in situ while the chondrule was partly molten. Composition and phase relations at the surface of chondrule X3 also suggest that it has been suspended in a reducing environment.

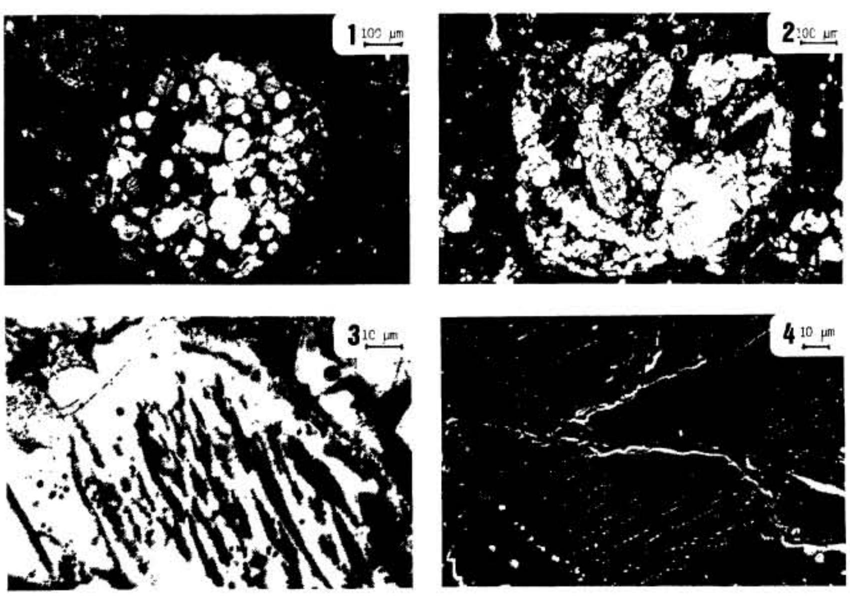
(d) Some chondrules bearing dusty olivine show other signs of reduction, e.g., low-FeO pyroxene. The reduction may have taken place between two igneous events [11], or, more plausibly, during moderately slow cooling. Crystallization of pyroxene following that of olivine after an intervening reduction episode seems a more straightforward explanation of poikilitic textures than either condensation [6,13] or shock-implanting [3].

(e) Reduction of olivine inside PO chondrules may have been widespread; dusty metal could be regarded as a frozen-in intermediate stage in a process which more commonly led to larger metal blebs inside olivine grains, or possibly loss of metal from the chondrule prior to complete solidification. Absence of reverse zoning of olivine would imply that conditions allowing metal to coalesce also allowed equilibration of olivines.

(f) Reduction during crystallization of chondrules implies an environment of falling $f(O_2)$. Among several possible mechanisms, slow reaction of the gas phase with condensed carbon seems a promising explanation for the change in $f(O_2)$.

References:

[1] Nagahara H. (1981) Nature 292, 135. [2] Rambaldi E.R. (1981) Nature 293, 558. [3] Rambaldi E.R. & Wasson J.T. (1982) GCA 46,922. [4] Boland J.N. & Duba A. (1981) Nature 294, 142. [5] Binns R.A. (1967) Amer. Mineral. 52,1549. [6] Blander M. & Abdel-Gawad M. (1969) GCA 33, 701. [8] Hoinkes G. & Kurat G. (1974) In: "Analyse extraterrestrischen Materials", p.265. [7] Tsuchiyama (1982) Chondrule Conf. Abstr., p.59. [9] Kurat G. & Kracher A. (1980) Z.Naturforsch. 35a, 180. [10] Scott E.R.D. & Taylor G.J., this volume. [11] Duba A. et al. (1982) LPSXIII, 188. [12] Nagahara H. (1982) Abstr. Chondrule Conf., p.47. [13] Olsen E. & Grossman L. (1978) EPSL 41,111.



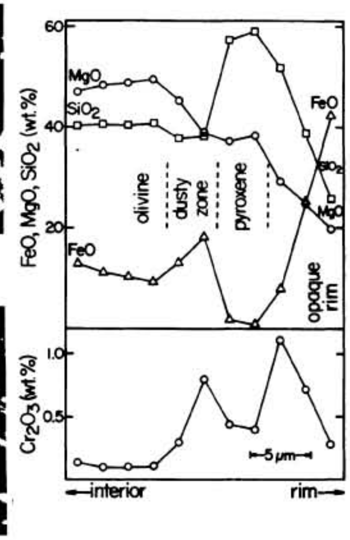


Fig. 1: Chondrule X1, dusty olivine is at the top. Fig. 2: Chondrule X3. Fig. 3: Detail of Fig. 1, showing "dusty" olivine. Fig. 4: Detail of olivine with annular dusty area in chondrule X3 (Fig.1-3 transmitted light, Fig.4 SEM photo). Fig. 5: Microprobe trace across surface of chondrule X3, near the bottom of Fig.2.