UNIQUE FORSTERITE IN CHONDRITES. I: LUMINESCENCE AND TEXTURAL FEATURES.

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Within the carbonaceous chondrites (CC) and unequilibrated ordinary chondrites (UOC), olivine compositions range from nearly pure forsterite to Fe-rich (1); most show a pronounced peak for nearly pure forsterite. Sporadic data exist for the common minor elements Ca and Mn but with no clear-cut trends. Considerable controversy exists over whether forsterite resulted from liquid crystallization, condensation (2,3) or a combination (4,5). Nagahara (6) and Rambaldi (7) have described textural and chemical evidence indicating that some olivine cores of chondrules in UOC are relic grains which have been preserved through the chondrule forming process. These grains are characterized by a cloudy appearance and reverse chemical zoning. Cathodoluminescence reveals another type of forsterite which is unclouded, has a unique chemical signature, is a component in all C2, C3 and UOC, and which provides direct mineralogical evidence for olivine precursors of chondrules. Similar luminescent olivine is present in one enstatite chondrite (Kota Kota, (8)) and one C1 (Orgueil) but chemical data are too sparse for current discussion.

Samples - To date we have examined thin sections of Allende CV3, Ornans CO3, Mighei, Boriskino, Murchison, Belgica 7904 CM, Krymka, ALHA 76004 LL3, Tieschitz H3. All were examined with a rapid microprobe survey, cathodoluminescence photography, and by detailed microprobe analysis of olivine: (2σ detection level in ppmw oxide follows element); Na(50), Al (85), P (40), Ca (65), Ti (65), Cr (75), Mn (80) and Ni (150).

Luminescence textures - Although most olivine and pyroxene in meteorites shows no cathodoluminescence in the visible spectrum, nearly pure forsterite and enstatite show various hues and intensities which are probably controlled by variable concentrations of transition metals. Within the CC and UOC some olivine is conspicuous by its blue to bluish-red luminescence under a focused electron beam which correlates with chemical features to be described. It is important to emphasize that the color goes bluer as the electron density increases, and the blue/red distinction is made for a focused spot; color photography also depends on processing. Other common phases which show distinctive luminescence in the chondrites are enstatite and Na, Ca, Al-rich glass, but each shows a distinctive hue. We illustrate some textures observed on luminescence photos in the line drawings of Fig. 1. In contrast to relic grains described by Nagahara (6) and Rambaldi (7), the blue olivines are generally free of inclusions unlike the surrounding Fe-rich olivine of the chondrule. The C3 chondrites contain blue olivine grains which are typically large and subhedral with a rind of red or dark olivine with higher Fe which in turn is bounded by the fine-grained matrix (Fig. 1a-e, Allende). Relatively common are aggregates of several of these grains forming a loose cluster (Fig. 1d). The blue subhedral cores show embayments and complex net-like fracture systems filled with non-luminescing olivine within which are tiny opaque inclusions. Chondrules are often associated with Na,Ca,Al-rich glass which either surrounds or penetrates into fractures. The C2 chondrites show blue olivines which are usually anhedral and rarely surrounded by a continuous Fe-rich rind (Fig. 1a-e, Murchison). Because the blue core abuts against the fine-grained matrix, no apparent interaction (diffusion) has occurred with the matrix. Among the UOC about half the chondrules contain blue olivine ranging from large (0.5 mm) anhedral grains to small subround grains (Fig. 1a-e, UOC). All show normal zoning to Fe-rich olivine as indicated by the blue luminescence grading to red then disappearing in a narrow zone giving a sharp luminescence boundary: e.g. Fig. 2 for Krymka. These blue-red grains may either be surrounded by the polycrystalline chondrule (Fig. 1d) or less commonly by matrix (Fig. 1a). Pale luminescing Na,Ca,Al-rich glass often is associated with olivine and one example has been noted with angular blue olivine within a chondrule of this glass. Many blue grains have embayments revealed by reddish or no luminescence and two grains (Fig. 1a,e) have fractures filled with dark luminescing olivine like those common in C3 chondrites.

Chemical features - All the relic blue forsterites from the UOC and CC have the same general features, but there may be minor distinctions. The following overall ranges characterize the forsterites: Al_2O_3 900-3000 ppmw; CaO 0.3-0.6 wt.%; TiO_2 400-800; MnO 50-300; Cr_2O_3 900-2200; FeO 0.5-1.5 wt.%; Ni,Na,P < 100 ppmw. These ranges include most of the blue olivines from the CC and UOC; however exceptions do occur e.g. one grain in Allende has 0.45 wt.% Al_2O_3 and FeO values below the quoted range. Each blue grain is homogeneous from its center to edge of blue boundary; variation does occur among grains. The steep zoning to more Fe-rich olivine leads to a discontinuity on element plots and luminescence photographs where color correlates with concentration changes (Fig. 2).

Discussion - The blue forsterite is easily recognized in chondrites, and its ubiquity implies that it was a pervasive component either in the solar nebula or in a larger part of the Universe. Its occurrence within chondrules of UOC as apparent relic grains provides evidence that it predated at least some chondrule formation. The various textures of the blue grains in the different types of chondrites indicate different histories prior to incorporation into the respective meteorites. Thus for the C3 chondrites the blue forsterite cores have survived intact as shown by their near euhedral shape. We suggest that the more Fe-rich olivine forming the rind and fissures has been added to the blue core and portions of the blue core were removed possibly by dissolution. This Fe-rich olivine is in crystallographic continuity with the blue core. For C2 meteorites this sequence also included fracturing prior to incorporation into the meteorite matrix giving the incomplete red rims and angular grains. In UOC the blue grains, although sometimes forming chondrules, more commonly form a small portion of a larger Fe-rich chondrule. The accompanying abstract in this volume examines the chemical features of these blue olivines as possible indicators of pre-chondrule conditions. NASA NAG 9-47.

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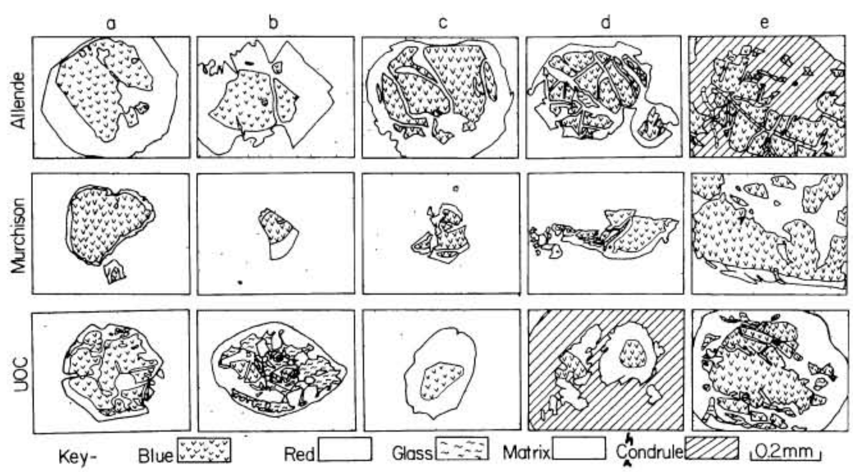

Fig.1

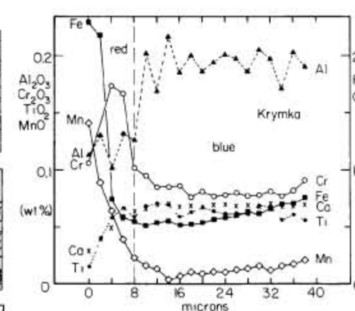

Fig. 2

Fig 1. Textures of blue and red olivine shown by luminescence photographs. UOCa,b=Tieschitz, c,d=Krymka, e=ALHA 76004. Most red or dark olivine is crystallographically continuous with blue cores.

Fig 2. Step scan across blue-red boundary in Krymka.