OLIVINES IN THE KABA CARBONACEOUS CHONDRITE AND CONSTRAINTS ON THEIR FORMATION X. Hua[1,2] and P. R. Buseck[1], [1]Depts. of Geology & Chemistry, Arizona State University, Tempe, AZ 85287 USA. [2]Central Laboratory, China University of Geosciences, Wuhan, PRC.

INTRODUCTION Kaba is unique in containing almost pure fayalitic olivine ($Fo_{0.1}$) [1]. Its coexistence with pure forsterite (up to $Fo_{99.6}$) and normal (Fo_{92} to Fo_{59}) and reversely ($Fo_{0.4}$ to $Fo_{4.7}$) zoned olivines suggests that the Kaba olivines are in thermodynamic disequilibrium and experienced a complicated history. The fayalite is sufficiently pure that it is unlikely that it could have been produced by fractional crystallization. A gas-solid reaction under oxidizing conditions (H_2O/H_2 ratio ~10) is probably responsible for its formation.

OBSERVATIONS Kaba fayalite occurs in matrix, chondrules, and rims around CAIs. The fayalite in matrix occurs (a) as isolated euhedral crystals up to 85 µm across (Fig. 1), (b) grouped around cores of troilite and pentlandite with or without magnetite, and (c) "sandwiched" between sulfides. The zoned olivines also occur within matrix. The fayalite in chondrules and chondrule-like objects is more abundant than in matrix. It occurs within enstatite and barred forsterite chondrules and in thin (< 10 µm) rims surrounding some chondrules (Fig. 2). It is found in a rim (65 µm wide) around a chondrule-like object with a 200-µm core consisting of magnetite and dispersed troilite. Fayalite crystals also occur in accretionary dust mantles around type-A Ca-Al-rich inclusions. Pure forsterite occurs in chondrules, and some spindle-like fayalitic halos surround the Ni-rich metal inclusions within the forsterite [2].

Minor elements such as Mg, Mn, and Ni in the fayalite are of special interest because they provide information relevant to its origin. The Kaba fayalites contain from 0.02 wt % to 2.5 wt % MgO, but can reach up to 4.7 wt % MgO where the grains are smaller than 5 µm or sandwiched between sulfides. They contain 0.5 to 1 wt % MnO. In the fayalites with reversed zoning, MnO shows a positive correlation with MgO. NiO is close to the minimum detection limit of 0.05 wt %.

DISCUSSION Olivine of such high fayalite content is unknown in other meteorites. A major problem exists in understanding its formation and subsequent persistence without reequilibration with the coexisting forsterite. The presence of forsterite adjacent to fayalite indicates that Kaba could not have experienced high-temperature metamorphism subsequent to the development of the olivine assemblage; the low temperature is confirmed by the presence of phyllosilicates [3]. The occurrence of zoned olivines in the matrix is also in agreement with the above conclusion, because otherwise homogeneous compositional profiles would have developed. Coexisting forsterite and fayalite is a disequilibrium assemblage that could not have formed in place and retained the end-member compositions. The questions are where and how could these olivines have formed? Forsterite could easily have crystallized from a melt or by condensation, as is widely observed in, respectively, terrestrial rocks and other meteorites. The fayalite is more puzzling. It is difficult to conceive of a melt that is sufficiently free of Mg, Mn, Ni, and perhaps other divalent cations to allow almost pure fayalite to crystallize. Similarly, normal condensation processes in the solar nebula invariably produce forsteritic olivines [4,5]. The answer to this problem is not clear, but minor-element chemistry can provide useful information.

If the fayalite formed from a melt, as is typical of terrestrial olivines, then it would almost invariably contain appreciable quantities (several percent or more) of MgO and MnO. If the parent melt had been in equilibrium with metal or a sulfide such as pentlandite, then Ni would have entered the fayalite structure. Lack of appreciable Mg, Mn, and Ni in the fayalite indicates that it formed by another mechanism. Based on its low Ni content, we conclude that it is unlikely that the fayalite formed by reaction between metal and silicate. We also conclude that it is unlikely that the fayalite formed from a melt; condensation remains a viable alternative.

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A possible mechanism for the formation of fayalite is the reaction of a Si-bearing gas such as SiO with an Fe oxide such as magnetite. We therefore propose the following as a possible model for olivine formation within Kaba.

(1) According to the normal condensation sequence in the solar nebula, forsterite, enstatite, sulfides, and magnetite formed at low temperatures (<400 K) [4,5].

(2) Forsterite and enstatite moved to a dust-rich region such as possibly the mid-plane of the asteroid belt, where the temperature and fO_2 were high as a result of the high density and the evaporation of some O-rich dust [6].

(3) Enstatite was reheated enough to partially evaporate, releasing SiO gas. A possible reaction is:

$$2\,MgSiO_3\,(s) + H_2 = Mg_2SiO_4\,(s) + SiO\,(g) + H_2O$$

At this stage, metal inclusions within the forsterite began to be oxidized, producing Fe^{2+} and leaving the metal enriched in Ni. The Fe^{2+} diffused into the surrounding forsterite to form the spindle-like halos [2].

(4) Magnetite and sulfides reacted with SiO gas to form fayalite. A possible reaction is:

$$2\,Fe_3O_4\,(s) + 3\,SiO\,(g) + H_2O = 3\,Fe_2SiO_4\,(s) + H_2$$

(5) Fayalite then moved into a cooler region shortly after its formation, where it remained.

(6) Accretion of the Kaba meteorite took place at a rather low temperature (~400 K?), which gave different olivines no chance to react with one another.

Thermodynamic calculations indicate that in the absence of Mg, pure fayalite coexisting with magnetite and sulfides will form in an environment that has an H_2O/H_2 ratio equal to 10 [7] at a temperature of around 1200 K [5].

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Fig. 1 Diamond shaped fayalite crystals embedded in the matrix.

Fig. 2 Fayalite grains associated with sulfides and magnetite within a thin rim and wrapped in a chondrule.