CHONDRULE FORMATION AND VOLATILE RECONDENSATION RECORDED IN AN OPAQUE ASSEMBLAGE FROM THE BISHUNPUR CHONDRITE. Dante S. Lauretta and Peter R. Buseck, Arizona State University, Department of Chemistry & Biochemistry, Department of Geology, Tempe, AZ 85287-1604. dante.lauretta@asu.edu.

Abstract: We reconstruct the thermal and chemical history of an assemblage of opaque minerals in the Bishunpur LL3.1 ordinary chondrite. It consists of kamacite rimmed by troilite, fayalite, chromite, and maricite. Its bulk composition constrains the conditions of metal formation in a reduced chondrule interior. Its mineralogy and morphology reflect corrosion in a dust-rich nebular gas.

Introduction: We have continued our investigation of metal- and sulfide-rich assemblages in Bishunpur to determine the conditions of their formation [1]. Petrographic thin sections of Bishunpur were surveyed using optical microscopy, electron microprobe analysis, field-emission scanning electron microscopy, and chemical mapping using energy dispersive spectroscopy. Here we report the results of a detailed investigation of one of the largest assemblages in the matrix of Bishunpur (Figure 1).

Results: The bulk composition of this assemblage was measured using broad beam (100 μm) electron microprobe analyses. The bulk composition (atom%) is: 53.7% Fe; 22.1% O; 17.6% S; 2.7% Si; 1.3% Ni; 0.74% P; 0.68% Cr; 0.47% Na; and 0.24% Co. Mg, Al, K, Ca, Mn, and Ti are below detection levels.

The mineralogy of this assemblage was determined using focused-beam electron microprobe analyses and field-emmision scanning electron microscopy. The metal is Fe-rich kamacite (95.8 % Fe) containing 3.3% Ni, 0.7% Co, and variable amounts of P (0-0.1%) and Cr (0-0.3%). It is full of small silica (SiO_2), chromite ($FeCr_2O_4$), and graphite (C) inclusions. Alternating rims of troilite (FeS) and fayalite (Fe_2SiO_4) occur along the kamacite edge. Chromite is concentrated in a single layer. Anhedral grains of maricite ($FeNaPO_4$) and fayalite are associated with larger (10-20 μm) troilite grains. Fine-grained (<100 nm) troilite and fayalite occurs between the thin layers near the metal and in the center of the assemblage.

Discussion: This assemblage is composed entirely of siderophile (Fe, Si, Ni, P, Cr, and Co) and volatile (O, S, and Na) elements and lacks any detectable refractory lithophile elements (Mg, Ca, Al, and Ti). The bulk composition is consistent with formation by corrosion of an Fe alloy that contained 4.6% Si, 2.1% Ni, 1.2% P, 1.1% Cr, and 0.4% Co. We suggest that this metal formed at high temperature in the interior of a type-I, low-FeO chondrule. The chondrule melt was highly reducing as a result of graphite, diamonds, or organic molecules [2]. Remnants of this material are present as the graphite inclusions [3].

The bulk Fe/Si ratio of the assemblage constrains the conditions of metal formation. If the metal formed at 1873 K, the liquidus temperature of chondrules [4], then 4.6% Si in a liquid Fe alloy indicates an oxygen fugacity of $10^{-12.7}$ bars [5]. This value is very close to the oxygen fugacities determined for type-I chondrules from several different meteorites [6].

The first corrosion of the metal occurred when Si and Cr were internally oxidized. This process concentrated all the metallic Si and most of the Cr into the silica and chromite inclusions that are still dispersed throughout the metal. The banded layers and fine-grained mixtures of fayalite and troilite formed simulateously via the reactions:

$$2\ Fe + SiO_2 + O_2\ (g) = Fe_2SiO_4 \qquad (1)$$

and

$$2\ Fe + S_2\ (g) = 2\ FeS \qquad (2)$$

At standard solar nebula conditions troilite condenses ~200 K higher than fayalite. However, when the abundances of O and S in the solar nebula are both increased by 380x the two phases condense at 1375K. In addition, fayalite can form at 719 K, the condensation temperature of troilite under standard solar nebula conditions, if the O/S ratio is increased by 12.6x over solar. Thus, 1375 K represents an upper limit and 719 K a lower one for simultaneous formation of these two phases.

The presence of maricite provides additional constraints on the gas composition. Under standard nebular conditions Ca-phosphates are stable [7]. Maricite must have formed in a system that was depleted in Ca or enriched in Na. During type-I chondrule formation volatile elements such as Na, O, and S evaporated from the melt [8]. This assemblage formed in an environment that was enriched in these elements. Thus, the metal that formed in a chondrule interior was corroded by the volatile elements that were lost from the chondrule melt.

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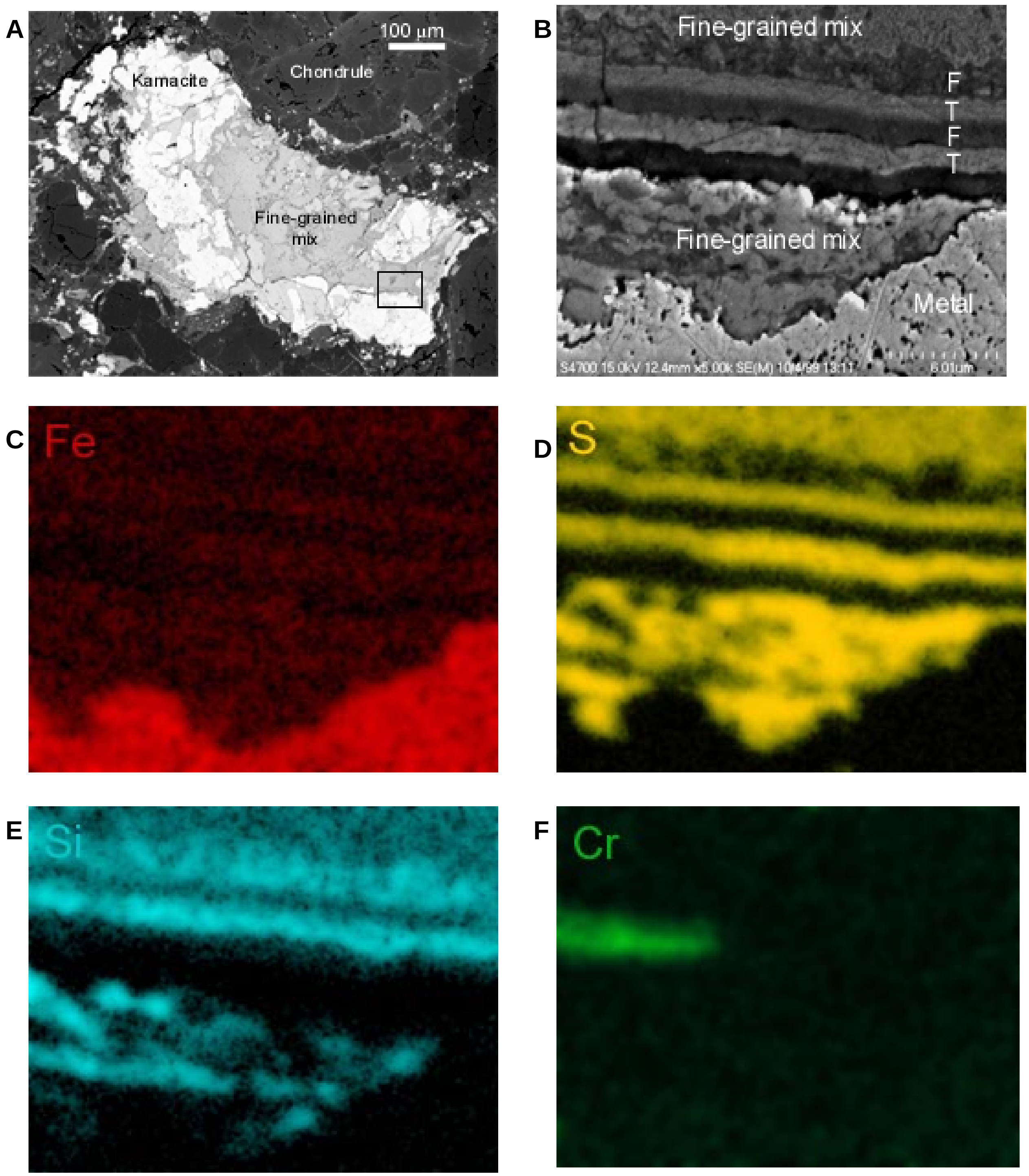

Figure 1. (A) Back-scattered electron image of the large opaque assemblage in Bishunpur. **(B)** Enlarged view of the boxed region in A. Note the inclusions in the metal. Banded layers of troilite (T) and fayalite (F) are present as well as fine-grained mixtures of these two phases. **(C)** Chemical map of Fe distribution. **(D)** The bands of troilite are evident in the S map. **(E)** The fayalite bands can be seen in the Si map. **(F)** A layer of chromite is detected in the Cr map sandwiched between the layers of troilite and fayalite.