CARBIDES IN ORDINARY CHONDRITES REVISITED. M. L. Hutson[1], A. M. Ruzicka[1], K. R. Farley[1], K. L. Schepker[1], R. C. Hugo[1], and L. E. Likkel[2], [1]Cascadia Meteorite Laboratory, Portland State University, Dept. of Geology, 1721 SW Broadway, Portland, OR 97201 U.S.A. (cmlpsu@pdx.edu; ruzickaa@pdx.edu), [2]University of Wisconsin-Eau Claire, Department of Physics and Astronomy, 105 Garfield Avenue, Eau Claire, WI 54701, U.S.A. (likkel@uwec.edu).

Introduction: The presence of iron-nickel carbide minerals (cohenite $(Fe,Ni)_3C$ and haxonite $(Fe,Ni)_{23}C_6$) was described for type 3 ordinary chondrites [1,2,3] with suggested formation via low-temperature aqueous alteration [3]. More recently, a carbide (initially identified as cohenite) was observed in two genomict breccias (Northwest Africa 5964, L3-6; Buck Mountain Wash, H3-6), associated with fragmental brecciation and evidence for shock sufficiently intense to create silicate shock melt [4,5]. Here we report the results of a combined EMP, SEM, EBSD, and TEM study on 26 H- and L-chondrites in an attempt to constrain the occurrence and origin of carbides in ordinary chondrites.

Occurrence of carbide: Of the 26 chondrites, we found carbide in 7 L genomict breccias, 1 H genomict breccia (Buck Mountain Wash, "BMW", H3-6), and one other chondrite (Northwest Africa 10454, L5/6). These are different kinds of rocks than the type 3 chondrites in which carbide was found previously [1,2,3]. All of the carbide-bearing genomict breccias contain type 3 materials as well as a substantial amount of silicate shock melt. Carbides are inhomogenously distributed, being absent in melt portions and instead concentrated in lithologies that contain more type 3 material. For example, in BMW, carbide is intergrown with nearly every metal grain in the shock-blackened type 3 lithology A [6] and is much less abundant in the main fragmental lithology dominated by higher-type material. Eighteen other chondrites, including variably metamorphosed chondrites, monomict breccias, samples with extensive shock melt that are not genomict breccias, L-melt rocks, and a heavily shocked chondrite (Northwest Africa 4860, L4 S6) all lack carbide. Most carbide grains are found either deeply within or at the edges of metal-carbide-troilite assemblages that contain kamacite and variable amounts of taenite and tetrataenite. Oxides, including possibly magnetite reported for the type 3 chondrites [1,2,3], are uncommon in most of the assemblages.

Chemistry of carbide: Previous reports of cohenite [4, 5], were based on EMP data that allowed for either cohenite or haxonite. A more precise EMP data set was subsequently obtained for NWA 5964 (L3-6) and BMW (H3-6) (Fig. 1). Not plotted in Fig. 1 are three carbide grains with high Co (up to 0.79 wt%) associated with high-Co kamacite (up to 1.5 wt%), nor three possible carbide grains with higher Ni contents (up to 16 wt%), in NWA 5964. Based on data for iron meteorites [7] and chondrites [3], most of the grains in NWA 5964 and in BMW are haxonite, although cohenite is present also in BMW. Five additional L chondrites containing carbide, including other genomict breccias and NWA 10454, were chemically analyzed via SEM. Carbide grains in these meteorites are also haxonite based on their Ni content.

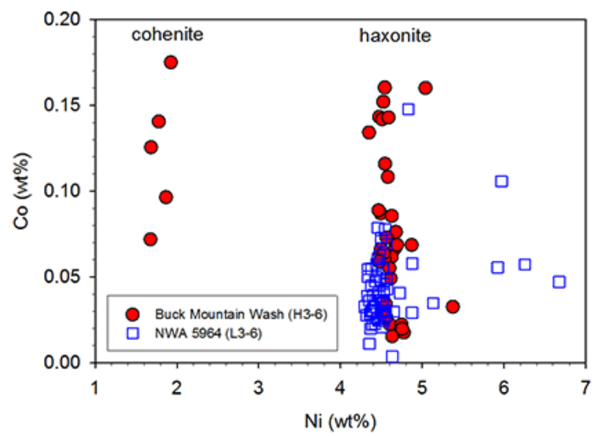

Fig. 1. Ni and Co contents in carbide grains in Buck Mountain Wash and NWA 5964 (EMP data).

Crystallography of carbide: Crystallography data were obtained with EBSD for carbide and associated grains in 16 different sites in NWA 5964 and Northwest Africa 6580 (Fig. 2). These data indicate that the carbides are a cubic phase similar to haxonite or Fe_4C, with haxonite most consistent with the data. Crystal orientations of carbide and associated metal were studied. The data show that {100} and {111} planes in coexisting haxonite and kamacite typically differ in orientation by large amounts (~15-45°), although for coexisting haxonite and taenite, one or both planes are commonly subparallel (to within 15°). Kamacite and taenite are typically in Widmanstätten orientation, with $\{111\}_{tae}$ parallel to $\{110\}_{kam}$. Tetrataenite orientations are always systematically related to that of taenite. EBSD data thus suggest preferred orientation relationships between haxonite and the various coexisting metal phases.

Carbide identification: A single carbide grain in NWA 5964 was examined with both EBSD and TEM. This grain indexed as haxonite or possibly Fe_4C with EBSD. A TEM section was made using FIB liftout.

Sample diffraction patterns at two orientations were compared to those of haxonite, cohenite, Fe_4C, and Fe_7C_3. The only match with the sample data was the haxonite pattern ($Fe_{20}Ni_3C_6$, space group Fm-3m lattice spacing 1.05 nm) (Fig. 3).

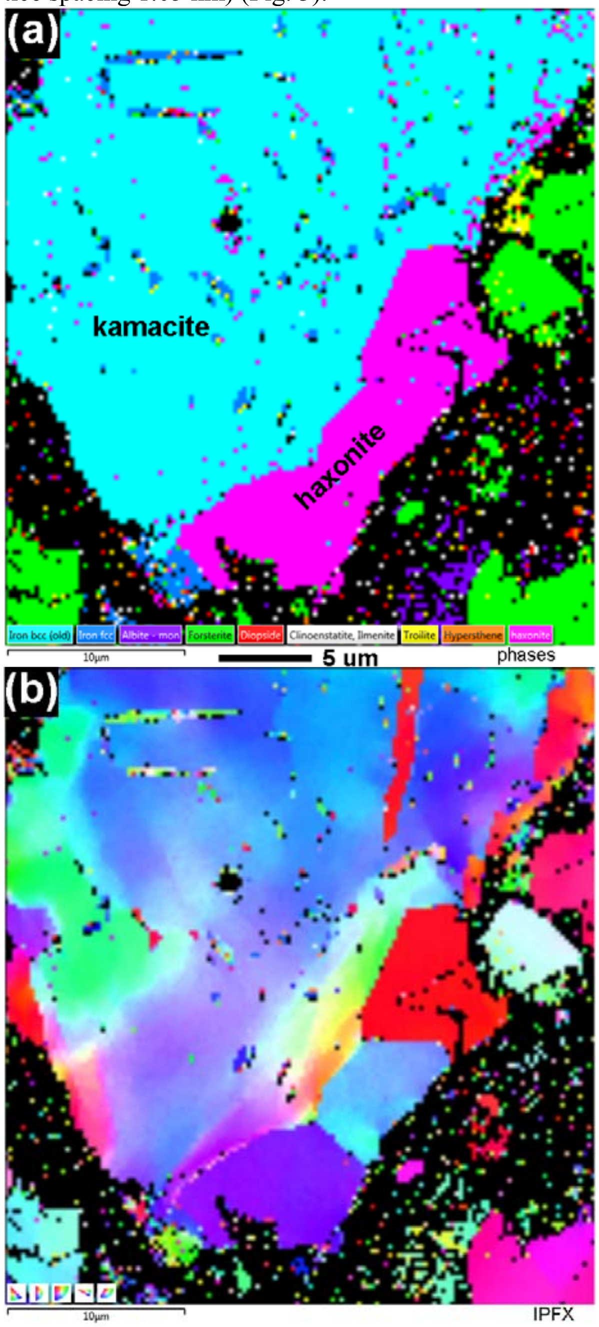

Fig. 2. (a) EBSD crystal structure phase map (pink = haxonite, light blue = kamacite) and (b) corresponding IPFX orientation map, of three subhedral haxonite grains at the edge of a metal grain in NWA 5964. Smooth color variations in the IPFX map indicate strain, which is concentrated in kamacite near haxonite.

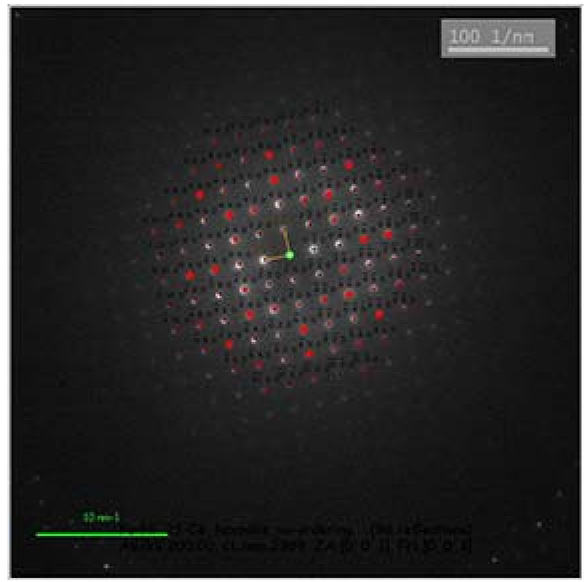

Fig. 3. A simulated haxonite diffraction pattern (in red) overlaid on the [001] zone axis pattern for a carbide grain in NWA 5964.

Discussion: We suggest that haxonite and cohenite formed as separate phases in metal during cooling after shock reheating, consistent with: preferred crystal orientation relationships; the presence of carbide within the cores of some metal grains; the drop in C solubility in metal with decreasing temperature [8]; our data that show elevated C in taenite compared to kamacite (consistent with a taenite precursor); and with the common occurrence of carbides in breccias that contain both significant melt and type 3 (likely C-rich) components. We speculate that shock heating caused breakdown of organic compounds and allowed diffusion of C into metal grains. The common association of carbide with zoned taenite or tetrataenite suggests carbide formation at low temperature during slow cooling (i.e., <100 ºC/Ma at ≤500 ºC in NWA 5964 and NWA 6580) [9], implying burial in the parent body of warm materials.

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