THERMAL HISTORIES OF CB METEORITES: EVIDENCE OF REHEATING FROM CR-RICH SULFIDES. P. Srinivasan, R. H. Jones and A. J. Brearley, Department of Earth and Planetary Sciences, 1University of New Mexico, Albuquerque, NM 87131, USA. psrinivasan@unm.edu.

Introduction: CB meteorites are a metal-rich group of carbonaceous chondrites. They contain 60-70 vol% of Fe,Ni metal, and a low abundance of matrix (<5 vol.%) that consists of impact melt [1]. There are two groups of CB chondrites: CBa meteorites have cm-sized metal and silicate grains and CBb have mm-sized metal and silicate grains [2,3]. Metal and silicate components in these meteorites are thought to have formed in an impact plume about 4.563 Ga [4,5]. A collision between two planetary bodies could create a plume, consisting of a dense vapor from which metal and silicate could condense. Siderophile element abundances in CBa meteorites suggest that one of the colliding planetesimals was metal-rich. [3,5,6,7]. After accretion of the different components, later impacts also affected the CB parent body, as evidenced by impact melt regions [3]. Impact glass from CBa Bencubbin gives Ar-Ar ages of 4.20 ± 0.05 Ga, possibly dating a major impact event [8].

Metal in CBs is kamacite, with nickel contents varying between 4.8-8.2 wt% in CBa to 4.1-14.8 wt% in CBb meteorites [9]. Metal grains contain sulfide inclusions, which dominantly consist of Cr-bearing monosulfide solid solution, MSS_1 $(Fe,Cr)_{1-x}S$. Most of these inclusions are homogeneous, while some show thin, sub-micrometer lamellae of daubreelite ($FeCr_2S_4$) [9,10]. We have examined Cr-rich sulfide textures and compositions in order to help constrain the thermal histories of CB meteorites.

Samples and Methods: We studied two CBa meteorites, Gujba and Weatherford, and two CBb meteorites, QUE94411 and HaH237. BSE images and quantitative chemical analyses were obtained with SEM and EPMA. We have also performed a FIB/TEM study of one exsolved sulfide grain in Gujba.

Results: In CBa meteorites, ~40% of the metal grains contain sulfide inclusions up to ~50 μm in diameter. The abundance of metal grains with sulfide inclusions is harder to estimate for CBb meteorites because of the small grain size. In most of the sulfide-bearing metal grains we studied, rounded sulfides are dispersed throughout the entire grain, while in others they are confined to smaller areas hundreds of microns in size. Sulfides also occur in arcuate textures [3] along metal grain boundaries (Fig 1A). Sulfide grains that show exsolution are typically 3-50 μm across (Fig 1B-D). Most exsolved sulfides have linear, parallel lamellae of daubreelite in an MSS_1 host (Fig. 1C,D). Sub-micrometer-sized metal blebs are observed in both homogeneous and exsolved sulfides [3] (Fig 1B,C). Some exsolved sulfides appear to contain three phases (Fig 1D); due to the small size of the lamellae, we have not yet identified the three phases using EPMA alone.

Overall, exsolved sulfides in CBa Gujba, CBa Weatherford and CBb HaH237 have similar textures. We have not observed any exsolved sulfides in CBb QUE94411. Gujba contains the highest abundance of metal grains that have exsolved sulfide inclusions, ~16%. Elongate sulfide grains (Fig 1C) and grains that show deformation are more common in Gujba than in the other meteorites. In all four meteorites metal blebs are present in less than 5% of sulfide inclusions.

Sulfide and metal analyses are shown in a Fe-Cr-S ternary diagram in Fig. 2. For fine-grained inclusions, with μm-sized phases, each EPMA analysis is a mixture of phases. The main difference between homogeneous and exsolved sulfide inclusions is their bulk chromium content. Analyses of homogeneous sulfides are either Cr-poor MSS_1, or lie between MSS_1 and Fe,Cr if they contain metal blebs. The average composition of metal-free homogeneous grains is Fe=57.6, Ni=0.23, Cr=4.1, S=36.7 wt%. For exsolved grains, each EPMA analysis is a mixture of MSS_1, daubreelite, and metal, when present. The bulk

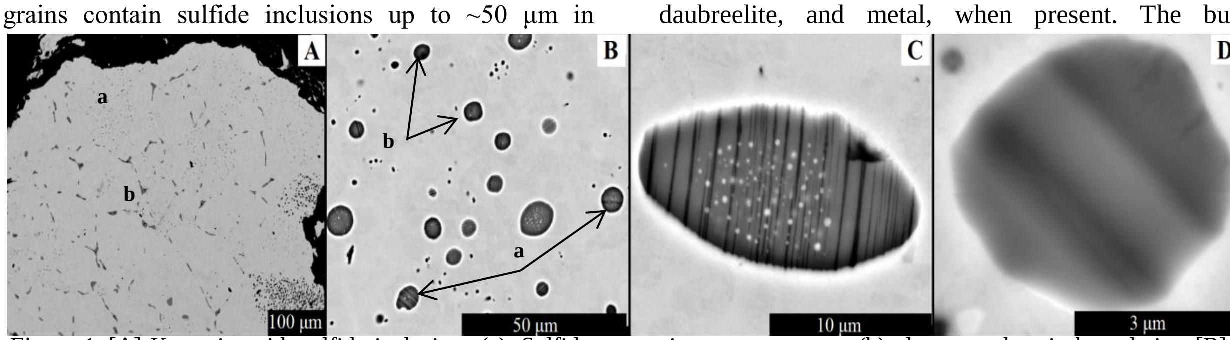

Figure 1. [A] Kamacite with sulfide inclusions (a). Sulfide occurs in arcuate textures (b) along metal grain boundaries. [B] Exsolved (a) and homogeneous (b) sulfide inclusions in kamacite. [C] Exsolved sulfide inclusion with linear, parallel daubreelite lamellae (dark grey) and metal blebs (white) in MSS_1 host (medium grey). [D] Exsolved sulfide inclusion with three regions that show different BSE contrast. In C and D, sulfide grains are embedded in kamacite (lightest grey).

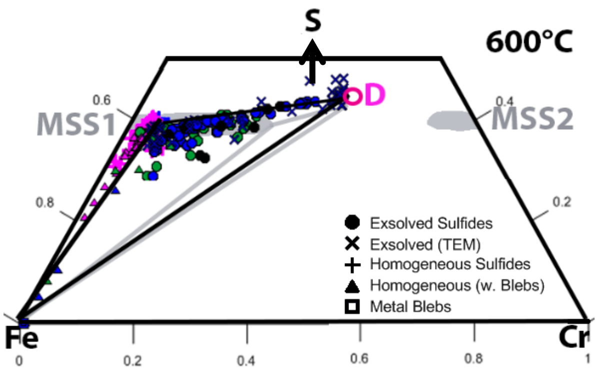

Figure 2. EPMA and TEM data for Gujba (blue), Weatherford (green), QUE94411 (pink), HaH237 (black). Grey areas and grey lines show MSS solid solution fields and phase relationships at 600 °C from [11]. Black lines show three-phase assemblages present in CB meteorites.

compositions of the exsolved sulfides lie within the two- or three-phase region defined by the component minerals. TEM analyses give average compositions for daubreelite of Fe=22.5, Cr=36.1, S=43.5 wt%, and for MSS_1 of Fe=57.2, Ni=0.14, Cr=6.1, S=36.1 wt%. Metal blebs in sulfide inclusions have an average composition of Fe=96.8, Ni=3.4, Cr=0.5 wt%. Host kamacite metal has approximately the same composition in all four meteorites, with Fe=93.1, Ni=6.1, Co = 0.30, Cr=0.24, P=0.34 wt%.

Mn and Cr contents of the sulfides show different trends for homogeneous and exsolved grains (Fig. 3). Homogeneous sulfides have low Cr contents, 2-6 wt%, and in QUE94411 and Weatherford, they have high Mn/Cr ratios with Mn contents up to 0.6 wt%. EPMA analyses of sulfides with daubreelite exsolution, from the two CBa meteorites and HaH237, are a mixture of MSS_1 and daubreelite, and have lower Mn/Cr ratios than the homogeneous grains. Homogeneous sulfides in Gujba have low Mn/Cr ratios, with higher ratios in the exsolved sulfides.

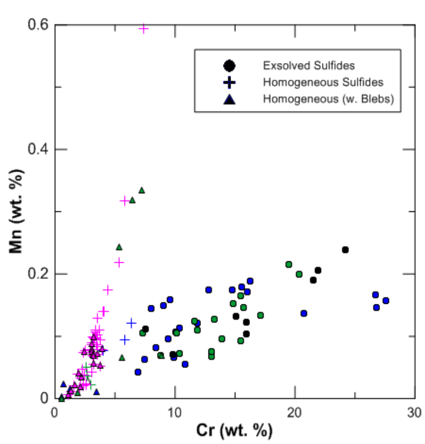

Figure 3. Mn vs. Cr contents of sulfide grains for the four CB meteorites: Gujba (blue), Weatherford (green), QUE94411 (pink), HaH237 (black).

Discussion: Exsolution can be the result of cooling or reheating. Several lines of evidence lead us to interpret the ubiquitous exsolution in CB sulfides as the result of reheating. This evidence includes high-pressure minerals and multiphase metal particles [9], metal grains with two-phase microstructures of taenite and kamacite showing heating to ~675°C [12,13], and Fe-Ni-S eutectic textures indicating heating to 950°C [14]. Differences in these temperatures provide evidence of heterogeneous heating throughout the parent body consistent with impact processing.

Reheating temperatures recorded by CB sulfides can be estimated with reference to the 600°C Fe-Cr-S phase diagram [11] (Fig. 2). The three phase assemblage of MSS_1, daubreelite, and metal observed in CBs exists at 600°C, but is not stable at higher temperatures [11]. The 3-phase assemblages in the CB sulfide inclusions are offset towards the left of the 600°C 3-phase stability field, because Cr solubility in MSS_1 is limited to ~6 wt% Cr vs. ~25 wt% Cr at 600°C. This indicates that the CBs have been heated to temperatures much less than 600°C.

All four CB meteorites that we studied have similar metal compositions, and metal commonly contains sulfide inclusions [9,10]. The Cr content of sulfides in QUE94411 is <6%, explaining the absence of exsolved sulfides in this meteorite. Homogeneous sulfides in QUE94411 have correlated Mn and Cr with a high Mn/Cr ratio. Gujba, Weatherford and HaH237 contain ubiquitous exsolved sulfides that originally had bulk Cr content greater than approximately 6% Cr. These similarities indicate related origins and thermal histories. We suggest that sulfide exsolution was the result of the last episode of reheating, possibly during late-stage impacts on the CB parent body, which caused mild, but ubiquitous, heating to temperatures much lower than 600°C, followed by rapid cooling to preserve the very fine grained scale of exsolution.

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