ORIGIN OF METAL IN THE CB (BENCUBBINITE) CHONDRITES.

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Introduction: Bencubbin (found in Australia, 1930) and Weatherford (found in Oklahoma, 1926) are primitive metal-rich chondrite breccias. Recently, two metal-rich meteorites with similarities to Bencubbin and Weatherford have been found. These are Hammadah al Hamra 237 (HH 237) from the Sahara and Queen Alexandra Land 94411 (QUE 94411), paired with QUE 94627, from Antarctica. These four meteorites constitute a new group called the CB (bencubbinite) chondrites [1,2]. One of the many intriguing characteristics of the CB chondrites is their metal compositions. Co is positively correlated with Ni and the concentrations are consistent with calculated condensation trends [1-4]. Additionally, some metal in HH 237 and QUE 94411 is zoned with Ni and Co decreasing from core to rim and the patterns are consistent with gas-solid condensation from the nebula [5-7]. Here we present a more comprehensive petrologic study of metal in the four CB chondrites in order to better evaluate its origin.

Results: The CB chondrites are aggregations of silicate and metal clasts, as are the other chondrites, but they have highly distinctive characteristics, including a high modal abundance of metal (60-70 vol. %). The metal in Bencubbin and Weatherford occurs as large (cm-sized) clasts. Each clast is homogeneous, but compositions are variable between clasts, ranging from 4.8-8.2 wt. % Ni and 0.1-0.5 Co. Ni and Co are positively correlated, with a solar Ni/Co ratio [3]. A few Si-bearing metal grains were found in Bencubbin with up to 2.5 % Si [3,4]. Troilite occurs as small (2-10 µm-sized) blebs within most metal and is Cr-rich, averaging ~2 wt. % Cr in Bencubbin and 4 % in Weatherford. Some troilite grains contain fine exsolution lamellae of daubreelite ($FeCr_2S_4$), but Cr appears homogeneous in other cases. Many metal clasts appear to be aggregates of smaller metal grains. In some aggregates, the boundaries between the grains are filled with Cr-bearing troilite, similar in composition to the blebs. Metal in QUE 94411 and HH 237 is much smaller in size (up to mm-sized). It overlaps in composition with Bencubbin metal [7,8,9], but appears to be more complex. It ranges (wt. %) from about 4.1-14.8 Ni (Table 3) and occurs as three major textural-compositional types: (1) large mm-size metallic aggregates, (2) small 100-300µm, homogeneous irregular grains and (3) small compositionally zoned grains (Fig.). **(1) The large aggregates** consist of smaller metal grains with inclusions of µm-sized blebs of Cr-bearing troilite (Fig.). In some cases, the troilite occurs at boundaries between the metal grains within the aggregates. These features are similar to those in the large cm-size metal aggregates in Bencubbin and Weatherford. The troilite blebs have an average Cr content of ~2-2.5 %, similar to that in Bencubbin. Cr is homogeneously distributed in most troilite, but in some cases the blebs have fine exsolved daubreelite. A fine (sub-micrometer) rim of high-Ni metal is present around some troilite blebs and some troilite blebs contain sub-micrometer-size inclusions of high-Ni metal. Another, less common inclusion that is present in some large metal aggregates is a silica-rich material. It occurs as small (<10 µm) spherical blebs generally associated with small troilite and, in some cases, enstatite. Another important feature of the metal aggregates is that the heavy nitrogen of the CB chondrites is associated with them, occurring in phases (e.g., high-Ni metal) at the boundary between the troilite blebs and their metallic host [10]. Some of **(2) the small homogeneous metal** fragments have compositions similar to those of the large metal aggregates; others are more Ni-rich, with up to 15 % Ni. **(3) The zoned metal** grains have Ni and Co decreasing, and Fe and Cr increasing, from the core to rim of the grain. Ni ranges (wt. %) from 15 in the cores to 4.5 in the rims, with a positive Ni-Co relationship. All metal in the CB chondrites plots along the solar Ni-Co trend, predicted for metal condensation from a solar gas at 1475 through 1375 K and 10^{-3} atm, and the zoned metal grains are no exception. However, Ni-Cr in the zoned metal does not closely follow the predicted condensation trend for metal, as well as the Ni-Co trend does. The Cr values are generally lower than the predicted trend. Additionally, the cores of zoned metal with high Ni contents fall short of having a solar Ni/Co ratio. Some of the zoned metal grains appear to be broken and the zoning is asymmetric, indicating that the zoning predated the breakage of the metal (Fig.). Similar zoning was described in metal in the CH chondrites (4,5,7,11).

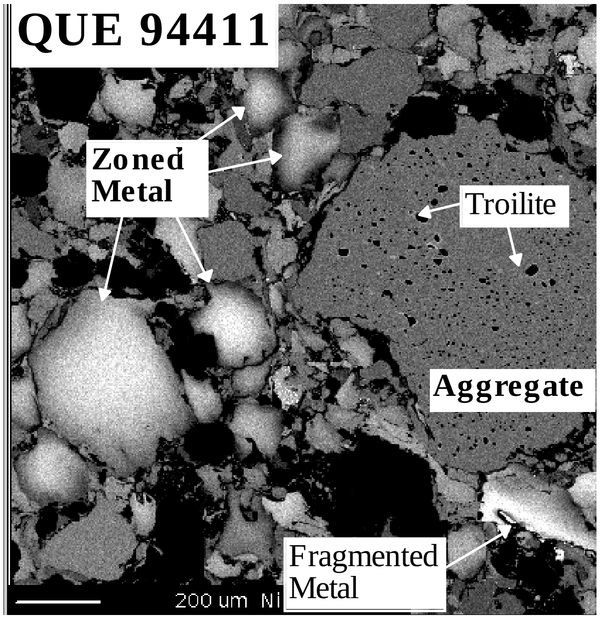

Fig. Ni X-ray map of the QUE 94411 CB chondrite. Brighter areas have higher Ni. Darkest areas are non-metal. Shown are zoned metal grains and a large metal aggregate with troilite blebs.

Discussion: The solar Ni/Co ratio and the zoning patterns in some CH and CB metal grains have been interpreted to be the result of nebular condensation [5-7]. However, the zoning patterns may also be consistent with diffusion of Fe from an external source, either a nebular gas or the surrounding material on the parent body. The occurrence of asymmetrical zoning in fragmental metal surfaces (Fig.) indicates that the zoning predates incorporation of the metal into the meteorite prior to final lithification, and suggests a nebular origin. The occurrence of high (up to 14%) Ni in the cores of some zoned metal suggests that these grains are metastable and would likely have decomposed to plessite structures if they were only mildly heated (above 300• C) during thermal metamorphism, arguing for a primitive origin [5,6]. However, all of the CB chondrites contain impact melt areas indicating that they were shock heated. It is difficult to envisage how the zoning survived this shock heating event. Cooling after the event would have had to be very rapid. It is possible that the zoning is the result of Fe diffusion during the impact heating event. If the zoning is primary and is not the result of impact heating, the CB chondrites are possibly the most primitive chondrites known. We plan to make laser ablation ICP-MS microprobe measurements of a large suite of elements (including Mo, Ru, Rh, Pd, Os, Ir, Pt, Ga, Ge and Cu) across the metal grains, to better understand their origin. The zoning profiles will include measurements of material (e.g., impact melt areas) adjacent to the zoned metal to search for evidence of diffusive exchange.

The metal aggregates differ from the zoned metal and appear to record a separate history. They are homogeneous, have low-Ni and contain troilite. Additionally, they are one of the carriers of anomalous heavy nitrogen in the CB chondrites, whereas the zoned metal has not been found to carry heavy nitrogen [10]. It is possible that the aggregates, having lower Ni, equilibrated with the nebula at lower temperatures than the high Ni cores of the zoned metal. One of the problems with a condensation origin for the metal aggregates is the presence of troilite blebs completely enclosed within the metal grains. According to equilibrium condensation models, troilite forms via reaction between Fe-metal and H_2S gas, at much lower temperatures than that at which FeNi metal condenses. This problem was reviewed by Newsom and Drake [3]. It is possible that the metal aggregates were initially porous, allowing metal surfaces to react with gaseous H_2S at lower nebular temperatures to form troilite. This is consistent with the occurrence of troilite along boundaries of the metal grains within some large metal chondrules in CB chondrites. Ni-rich rims around some of the troilite blebs in CB chondrite metal may also be an artifact of this reaction. It is also possible that S was dissolved in the early condensing metal and the troilite exsolved during cooling. The metal aggregates are a primitive component that occurs in all four CB chondrites, whereas the zoned metal occurs only in QUE 94411 and HH 237.

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