CHONDRULES OF THE VERY FIRST GENERATION IN BENCUBBIN/CH-LIKE METEORITES QUE94411 AND HAMMADAH AL HAMRA 237: CONDENSATION ORIGIN AT HIGH AMBIENT NEBULAR TEMPERATURES. Alexander N. Krot[1] (sasha@pgd.hawaii.edu), Anders Meibom[1], Sara S. Russell[2], Edward Young[3], Conel M. Alexander[4], Kevin D. McKeegan[5], Gary Lofgren[6], Jeff Cuzzi[7], Jutta Zipfel[8], and Klaus Keil[1]. [1]Hawai'i Institute of Geophysics & Planetology, School of Ocean & Earth Science & Technology, University of Hawai'i at Manoa, HI 96822, USA; [2] The Natural History Museum, SW7 5BD, London, UK; [3]Oxford University, UK; [4]Carnegie Institution, Dept. Terrestrial Magnetism, Washington DC, USA; [5]University of California, Los Angeles, USA; [6]Johnson Space Center, NASA, Houston, USA; [7]NASA Ames Research Center, USA; [8]Max-Planck-Institut fur Chemie, Mainz, Germany.

Introduction: Chondrules are generally believed to have formed in dust-rich regions of the solar nebular during multiple brief heating episodes (e.g., lightning, shock waves). The precursors of chondrules were solid materials that included dust grains and earlier generations of chondrules, all resting at ambient nebular temperatures below 650 K before melting [1]. The evidence in support of this model is: (1) relic grains inside chondrules, (2) coarse-grained igneous rims around chondrules, (3) independent compound chondrules, (4) porphyritic chondrule textures, (5) the relatively high abundance of moderately volatile elements (Mn, Na, K, S) in chondrules, and (6) rapid (10-1000°C/hr) cooling rates of chondrule melts [2]. The origin of chondrules of the very first generation remains one of the major unsolved mysteries in meteoritics. Here we present results on the mineralogy and chemistry of chondrules from the Bencubbin/CH-like chondrites QUE94411 and Hammadah al Hamra 237; O-isotope and trace element studies are in progress.

Mineralogy and Petrography: Hammadah al Hamra 237 (HH 237) and QUE94411 (QUE) paired with QUE94627 are metal-rich (~70 vol%) chondrites composed of three major components: Fe,Ni-metal grains, chondrules, and rare Ca,Al-rich inclusions (CAIs) (Fig. 1). Fine-grained matrix material attached to chondrules is absent [3-5]. Heavily hydrated matrix lumps composed of phyllosilicates, Ca-carbonates, framboidal magnetite and prismatic Fe,Ni-sulfides are very rare [Krot, unpubl.]. Virtually all Ni-rich (>7 wt% Ni) metal grains in QUE and HH 237 are compositionally zoned (Fig. 1b) suggesting a gas-solid condensation origin under relatively oxidizing conditions without subsequent melting and thermal metamorphism above 300°C [6-8]. The zoned metal grains contain high concentrations of platinum-group elements (PGE) suggesting that metal condensation took place in a solar nebula region which probably experienced complete vaporization [9]. CAIs are rare and mineralogically most similar to those in CHs [10]; the latter are generally characterized by isotopically normal Ca and Ti, the absence of $^{26}Mg^*$ (decay product of ^{26}Al) and have the most pristine O-isotopic compositions [11-13].

Chondrules have microporhyritic (MP), skeleteal-olivine (BO) and cryptocrystalline (CC) textures. Chondrules with porphyritic textures, relic grains in chondrules and igneous rims around chondrules are absent. Chondrules are relatively poor in FeO (BO and MP, 3.7±1 wt%; CC, 1.7±1 wt%) and highly depleted in Mn, K, Na, and S (<0.05-0.07 wt%), but have relatively high contents of Cr_2O_3 (MP and BO, 0.45±0.1 wt%; CC, 0.7±0.1 wt%) (Fig. 2). Metallic Fe,Ni nodules in chondrules are absent. The MP- and BO-chondrules are enriched in refractory lithophile elements (Ca, Al, Ti ~3-4xCI), whereas the abundance of these elements in CC-chondrules varies from 2xCI to <0.01xCI (below the detection limits of the electron microprobe: <0.05 wt% CaO, Al_2O_3, TiO_2) (Fig. 2). The abundance of refractory lithophile elements appears to correlate positively with the chondrule sizes: chondrules rich in Ca, Al and Ti (bluish in Fig. 1a) are generally larger than those with low concentrations of these elements (reddish in Fig. 1a). Some of the CC-chondrules occur as inclusions in chemically zoned Fe,Ni-metal grains (Fig. 1b). These chondrules are mineralogically and compositionally similar to those outside Fe,Ni-metal grains, but have slightly higher concentrations of Cr_2O_3 (1.1±0.5 wt%) (Fig. 3). Silicate inclusions compositionally similar to MP- or BO-chondrules are absent inside metal grains. The sizes of metal grains (25-300 µm) are comparable or larger than those of CC- (20-100 µm) and MP- and BO-chondrules (25-250 µm) (Figs. 1a,b) indicating the absence of aerodynamic size sorting during accumulation of the QUE and HH 237 parent asteroid.

Discussion: Thermodynamic modeling of equilibrium condensation of the chemically-zoned Fe,Ni-metal grains from QUE and HH 237 [8] and high concentrations of PGE in these grains [9] suggests that metal condensation took place under oxidizing conditions in a solar nebula region that had high dust/gas ratio (~10-40xSolar) and experienced complete vaporization. The absence of Fe,Ni-metal nodules inside chondrules and presence of chondrules inside chemically-zoned Fe,Ni-metal grains indicate that the chondrules formed at high ambient temperatures, prior to condensation of Fe,Ni-metal, most likely in the same nebular region. This interpretation is consistent with (1) the extreme depletion of chondrules in moderately volatile elements, (2) the Cr enrichment in chondrules and depletion in metal, and (3) the relative enrichment of chondrule silicates in FeO, which indicates formation under oxidizing conditions. This also implies that the depletion in moderately volatile elements of QUE and HH 237 is a condensation signature, not a result of evaporative loss during chondrule formation. The observed continuous range of concentrations of refractory lithophile elements may reflect fractional condensation and removal of the earlier formed chondrules or chondrule precursors from the hot chondrule-forming region. This removal must have occurred prior to condensation of moderately volatile elements (Mn, Na, K, S). The apparent positive correlation between the abundances of refractory lithophile elements and chondrule sizes may reflect an increase in the density of nucleation sites during formation of chondrules or chondrule precursors from the Ca,Al,Ti-rich to Ca,Al,Ti-poor. The absence of chondrules with porphyritic textures and absence of fine-grained matrix attached to chondrules suggest that chondrules crystallized from complete silicate melts in the dust-free environment (no crystalline silicate nuclei were present) [14, 15]. This means that either chondrules resulted from direct condensation from gas into liquid or that they formed during prolonged heating of gas-solid condensate precursors above liquidus temperatures that resulted in evaporation of fine-grained material. Because Fe,Ni-metal grains in QUE and HH 237 show no evidence for melting, the second scenario requires that melting of chondrules predated condensation of Fe,Ni-metal grains. If chondrules in QUE and HH 237 formed as liquid condensates, they will probably show (1) no Rayleigh-type fractionation of Mg, Si, Ca, and Fe isotopes (since these elements were not lost by volatilization during chondrule formation), and (2) pristine O-isotopic composition (plot along slope 1.0 on a 3-oxygen isotope diagram). Because chondrules in CBs escaped subsequent melting at lower ambient temperatures, which would probably result in melting of zoned metal grains, mixing of metal and silicates, enrichment in volatile elements, and formation of porphyritic textures, we infer that chondrules in QUE and HH 237 may represent chondrules of the very first generation.

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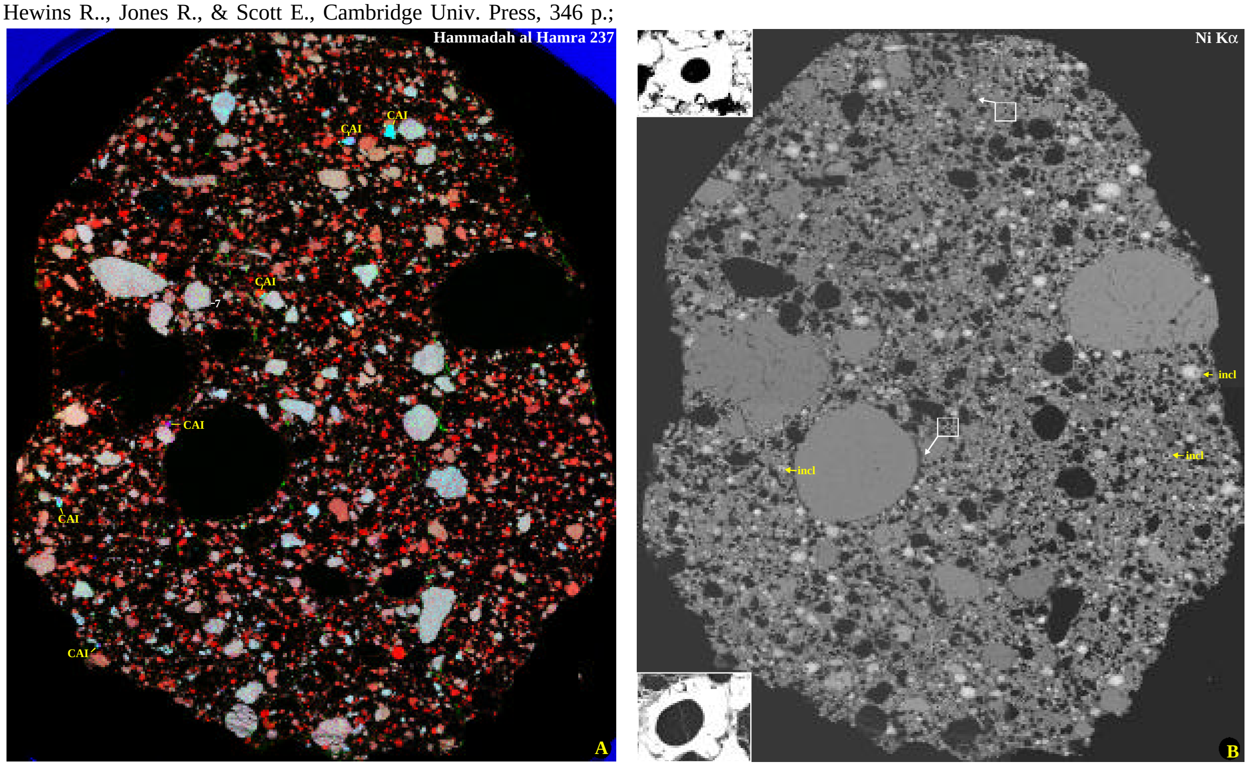

Fig. 1. A - Combined X-ray elemental map in Mg Kα (red), Ca Kα (green) and Al Kα (blue) of the polished thin section of HH 237. Ca,Al-rich inclusions (CAI) appear blue. Skeletal-olivine and microporhyritic chondrules are large and have bluish colors; cryptocrystalline chondrules are smaller and have reddish colors. B - X-ray elemental map in Ni Kα. Many Fe,Ni-metal grains are chemically zoned; some of them contain inclusions of silicate spherules (see insets) which are mineralogically similar to CC-chondrules.

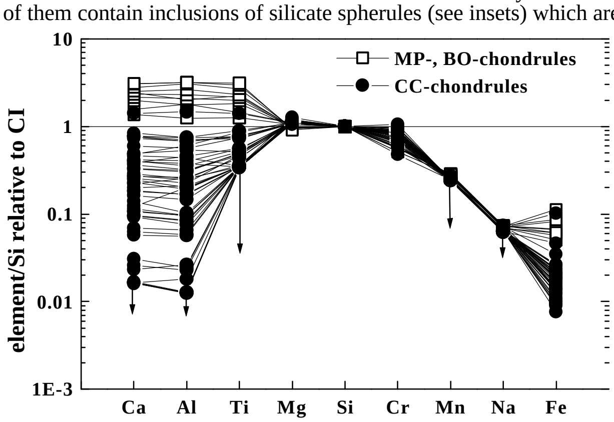

Fig. 2. Bulk compositions of skeletal-olivine (BO) + microporhyritic (MP) and cryptocrystalline (CC) chondrules in QUE and HH 237. MP- and BO- chondrules are enriched in refractory lithophile elements (Ca, Al, Ti) by ~2-4xCI; CC-chondrules show continuous range of concentrations of these elements from ~2xCI to <0.01xCI. MP- and BO- and CC-chondrules are highly depleted in Mn, Na and S. Arrows indicate element concentrations below detection limits.

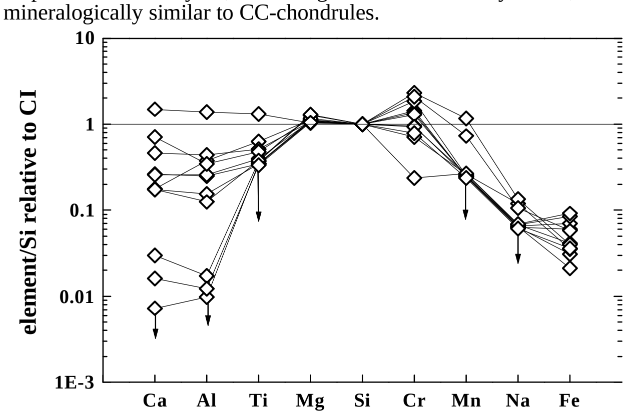

Fig. 3. Bulk compositions of silicate spherules enclosed in chemically zoned Fe,Ni-metal grains from QUE and HH 237. The silicate spherules are compositionally similar to CC-chondrules from the host meteorites (see Fig. 2).