CONSTRAINING THE NATURE OF TYPE-I CHONDRULES FROM UOC'S: A DETAILED IN SITU PETROLOGIC AND GEOCHEMICAL INVESTIGATION. H. C. Connolly Jr.[1,2,3,4], H. Barcena[1,3], K. Domanik[4], K. Nagashima[5], G. R. Huss[5], R. D. Ash[6], M. K. Weisberg[1,2,3]. [1]Dept. Physical Sciences, Kingsborough Community College of CUNY, 2001 Oriental Blvd., Brooklyn N.Y. 100235, USA; [2]Dept. of Earth and Environmental Sciences, The Graduate Center of CUNY, 365 5th Ave., New York, New York, 10016, USA; [3]Dept. Earth and Planetary Sciences, AMNH, Central Park West, New York, NY 10024, USA; [4]Univ. of Arizona, LPL, Tucson, AZ 85721, USA; [5]HIGP, Univ. of Hawai'i at Mānoa, Honolulu, HI 96822 USA; [6]Dept. of Geology, Univ. of Maryland, College Park, Maryland 20742, USA (chondrule@haroldconnolly.com).

Introduction: Constraining the redox conditions experienced by ferromagnesian chondrules during their formation has been the subject of numerous investigations [1-5]. Of particular interest to our research is constraining how type-I, FeO-poor chondrules, were reduced and what processes contributed to their origin.

Hypotheses [1-5] to explain the reduced nature of type-I chondrules are: (1) Molten chondrules reacted with ambient nebular gas, which was solely responsible for their reduced nature. (2) Their precursors contained reduced C, which, upon melting, reacted with the molten silicate liquid to produce reduced micro-environments. In 2, ambient nebular gas had little affect on their redox state. (3) Combination of 1 and 2.

To test the above hypotheses, we have begun a detailed in situ petrographic, geochemical, and oxygen-isotopic investigation of silicate and FeNi metal grains in type-I chondrules from UOC's (3.0-3.05). We present our preliminary results below.

Analytical methods: Thin sections of MET 00526,9 and QUE 97008,14 (both L3.05) have been investigated. BSE-images, x-ray maps, and major and minor element abundances of silicates, oxides, opaques, and glasses were analyzed with the SX-100 at the LPL. X-ray maps were created at high resolution, *following* quantitative analyses. Trace siderophile element abundances (SEA) of FeNi metal were determined with the LA-ICPMS Finnigan Element 2 at the University of Maryland following the techniques of [6]. Oxygen isotopes (O-isotopes) abundances in olivine were analyzed with the Cameca ims 1280 ion microprobe at the University of Hawai'i at Mānoa [7].

Results and Discussion: *General Petrography:* A total of 16 chondrules have been investigated. We focused on collecting data from type-I chondrules. Preference was initially given to metal-rich ones and objects that we considered petrographically unusual (Fig. 1). The chondrules studied are type-IA, -IAB, -IB and two "type-II". The majority of chondrules have PO textures (73%; 2 with hopper olivines) with 1 BO, 2 BO/PO. At least 7 chondrules contain relict grains, either dusty Fa-rich or Fo-rich olivines. Metal is present in varying amounts (up to ~ 40 vol%, Fig. 2) in all but 2 chondrules. Two chondrules are different (MET 00526,9 Ch1 and Ch2, Fig. 1) in that one is an Al-rich chondrule and the other is a 'type-II' chondrule with relict dusty olivines apparently overgrown with spinel ($MgAl_2O_4$). Major- and minor-element zonation in olivine phenocrysts from type-I chondrules is typical in that the zoning within individual crystals is normal and subtle, showing only variations of 2% Fa with < 1000 ppm variation in CaO and a few 100 ppm in Cr_2O_3.

Siderophile trace elements: The SEA in FeNi metal ranged from essentially below detection limit for everything but Fe, Ni, Co, and Cr to a flat pattern at or slightly above 10x CI abundances (QUE Ch 2, Ch4, Ch11) in most elements. Some grains show a clear depletion in volatile elements (e.g., Au). Metal grains within some chondrules do show inter-grain variations in the SEA, which may be the result of weathering.

O-isotope abundances: O-isotope abundances were analyzed for chondrule olivines and spinels in 16 chondrules (66 analyses). Overall, the majority of the data plot on or above the TF line in the 3-isotope diagram (Figs. 3&4), consistent with bulk UOC values and the findings of [8,9]. Several chondrules show important exceptions in their O-isotope abundances to others in the same chondrite. An example is MET 00526,9 Ch2, an Al-rich chondrule, which has olivines with $\Delta^{17}O$ ~ -12‰. MET 00526,9 Ch1 is spinel-rich, 'type-II' but the spinel and olivines have very similar O-isotopes, suggesting that they grew from the same melt. The spinels appear to be overgrowths on the olivines, which is not intuitive for MgAl-rich spinel, which should have been the liquidus phase. QUE 97008,14 Ch 4 has nearly uniform O-isotopes abundances in olivines with $\Delta^{17}O$ ranging from -3 to -4‰, plotting between the TF and CCAM. It is also the most FeNi metal rich with SEA ~ 10x CI. QUE 97008,14 Ch 2 has a Fo-rich relict olivine that is ^{16}O-enriched and heterogeneous in its O-isotopes ($\Delta^{17}O$ ~ -11 to -8‰), which correlates with Fo content. All but one phenocrysts have uniform O-isotopes ($\Delta^{17}O$ ~ +1‰).

Conclusions: Our combined *in situ* investigation has yielded some petrological and isotopically exciting results. Although the majority of chondrules studied have O-isotope abundance similar to what might be expected for UOC's, several do not. The 10x CI

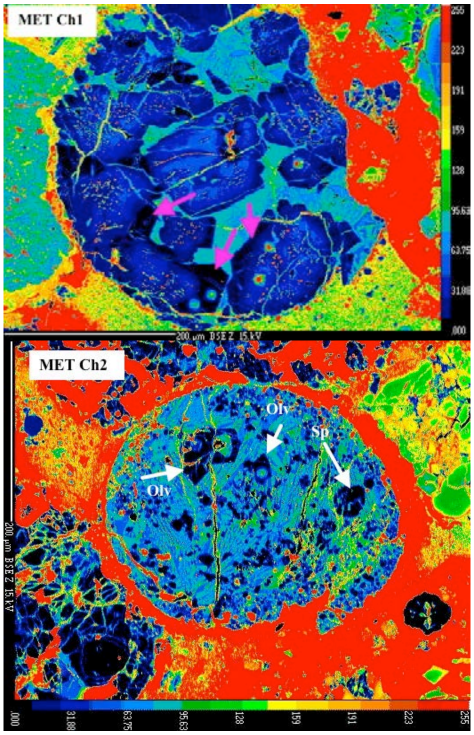

Figure 1. Color-enhanced BSE images of a Type-II, spinel-rich (upper) and an Al-rich chondrule (lower) from MET 00526,9. Arrows point to spinel 'overgrowths' on dusty relict olivines (Ch 1) and olivines/spinels (Ch2). Blue = MgO, Red = FeO.

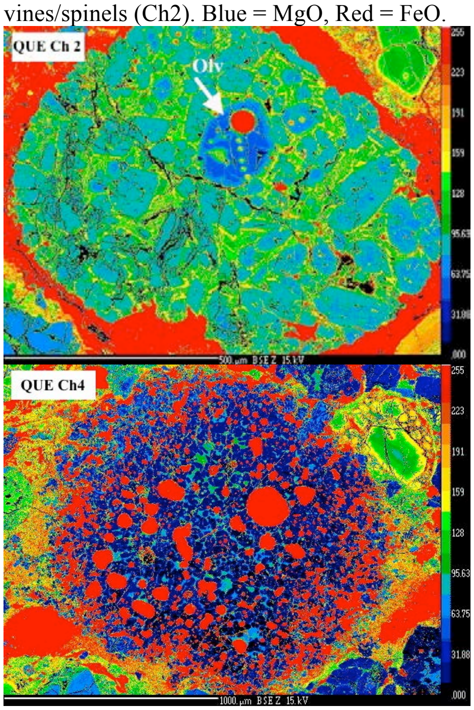

Figure 2. Color-enhanced BSE images of type-I chondrules from QUE 97008,14. Ch 4=metal-rich.

abundances of siderophile elements combined with the ^{16}O-enrichment that some chondrules have, e.g., QUE 97008,14 Ch2 &Ch4, may suggest that their

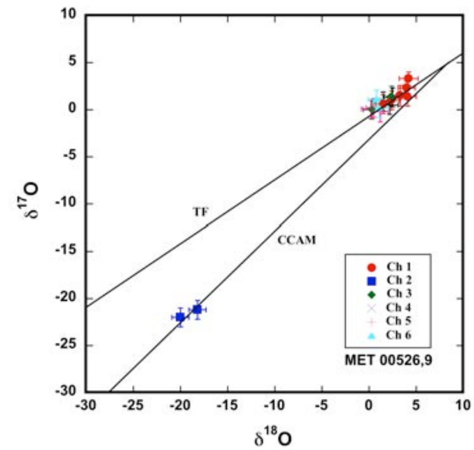

Figure 3. Oxygen isotope diagram for data from olivines and spinels from chondrule in MET 00526,9.

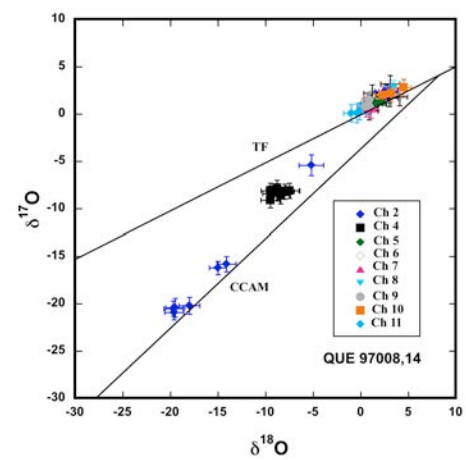

Figure 4. Oxygen isotope diagram for date from olivines from chondrule in QUE 97008,14.

precursors contained metal nuggets rich in siderophile elements [3] and ^{16}O-rich silicates, potentially from a previous generation of chondrule formation. Reduction of FeO likely occurred in many of the chondrules, in particular chondrules such as QUE 97008,14 Ch 2, to produce at least some of the siderophile-poor FeNi metal. The presense of C within chondurle precursors could explain the redox state and potentially the ligher O-isotope values of some type-I chondrules due to reduction, which also produces mass dependent fractionation [5]. We will expand out investigation to additional chondrules and potentially new chondrites.

References: [1] Connolly et al., (1994), *Nature*. [2] Zanda et al., (1994) *Science*. [3] Connolly et al. (2001) *GCA*. [4] Lauretta et al. (2006) *MESS II*. [5] Barcena and Connolly (2012), this meeting. [6] Brenan et al. (2003) *EPSL*. [7] Makide et al. (2009) *GCA*. [8] Clayton et al. (1991) *GCA*. [9] Kita et al. (2010) *GCA*. NASA #NNX10AG46G (HCCJr).