

## THE PETROLOGY OF OPAQUE ASSEMBLAGES IN UNEQUILIBRATED ORDINARY CHONDRITES

S. P. Alpert<sup>1,2</sup> (salpert@amnh.org), D. S. Ebel<sup>1,2,3</sup>, M. K. Weisberg<sup>1,2,3</sup>, N. T. Kita<sup>4</sup>, G. Siron<sup>4</sup>, and K. Fukuda<sup>4</sup>.

<sup>1</sup>Dept. of Earth and Planetary Sci., American Museum of Natural History, New York, NY 10024, USA, salpert@amnh.org. <sup>2</sup>Earth and Environmental Sci., CUNY Graduate Center, New York, NY 10016, USA. <sup>3</sup>Dept. Physical Sci., Kingsborough Community College, CUNY, Brooklyn, NY 11235, USA. <sup>4</sup>WiscSIMS, Dept. of Geoscience, University of Wisconsin-Madison, Madison, WI 53706, USA

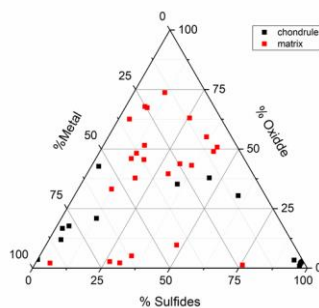
**Introduction:** Variations in iron content among chondrites suggest that metal-silicate fractionation was a key process in the early protoplanetary disk. Previous work [1] on CR chondrites determined relationships between FeNi metal textural setting (in chondrules or isolated in matrix) and concentrations of trace siderophile elements, concluding that some metal nodules were expelled from chondrule melts and partially vaporized/recondensed, while others follow no interpretable trend. To understand and constrain such processes, we began a study of the opaque assemblages (OAs) in ordinary chondrites (OC). OAs range from nearly pure to variable mixtures of metals, sulfides, oxides, and in rare cases silicates [2, 3, 4, 5]. Here we provide detailed petrologic descriptions, modal abundances, and mineral compositions of 37 OAs in the unequilibrated OC, Semarkona (LL3.01).

**Methods:** Element x-ray intensity maps were collected in WDS stage mapping mode using the Cameca SX100 electron microprobe (EMP) at the AMNH on four polished sections and a suite of standards at 1 $\mu$ m/pixel resolution, 15ms dwell, 40nA current. Maps were run through a machine learning algorithm which identifies the mineral phase of each pixel based on standards [6]. Quantitative point analysis was conducted on the EMP for Mg, Fe, Cr, Si, S, Na, Co, Ti, Al, P, Ni, Mn, and Ca at 20nA and 15kV, with a 1 $\mu$ m spot size. Oxygen isotope analyses of olivine grains were obtained using ~12  $\mu$ m spot size according to the method similar to [8]

**Results:** OAs occur in matrix (sharply bound, 300 to >2000  $\mu$ m in size, generally round, often mineralogically layered) and associated with chondrules (either completely interior to chondrules or as full or partial rims). Rim OAs range from matrix OA size down to micron size. OAs are dominantly kamacite with avg. wt. % 85 Fe, 7.5 Ni; taenite 45 Fe, 49 Ni; magnetite; troilite or mono-sulfide solution (MSS). Chondrule interior OAs are similar to matrix, but some matrix OAs contain fine-grained silicates: either matrix-like olivine or olivine-rich microchondrules as in [7]. We measured oxygen isotopes in 5 microchondrules in one OA, finding  $\Delta^{17}\text{O}$  from  $-1.4 \pm 0.3\text{‰}$  to  $+0.3 \pm 0.2\text{‰}$ . Negative  $\Delta^{17}\text{O}$  values are most similar to  $^{16}\text{O}$ -rich relict grains in PO chondrules in LL3's [8]. OAs in both textural settings have a range of mineral abundances (Fig. 1). Matrix OAs exhibit a higher abundance of oxides (75%) than chondrule OAs with nearly pure metal or pure sulfide OAs only being found associated with chondrules.

**Discussion:** The OAs exhibit a wide range in both structure and mineralogy, suggesting different histories and varying degrees of oxidation/sulfidation. OAs enclosed in chondrules (Fig. 2) were likely shielded from both nebular and parent body oxidation. Matrix OAs within a few  $\mu$ m proximity exhibit wide composition ranges, suggesting each formed as an independent object prior to lithification. OAs in chondrules and matrix must have a close relationship. Either matrix OAs were immiscible droplets expelled from chondrule melts, or OAs formed as pre-existing solid nodules, some of which were then incorporated into chondrule melts. Unmelted OAs will be examined in the future by field emission scanning electron microscopy to resolve their fine-grained mineralogy and determine whether they exhibit textures indicative of direct condensation from a gas.

**Acknowledgements:** Research was supported by AMNH and NASA Emerging Worlds grant NNX16AD37G (DE). **References:** [1] Connolly H. C. Jr. et al. (2001) *Geochim. Cosmochim. Acta* 65:4567-4588. [2] Zanda B. et al. (1994) *Science* 265:1846-1849. [3] Rubin A. (2005) *Geochim. Cosmochim. Acta* 69:4907-4918. [4] Campbell A. et al. (2005) In *Chondrites & the Protoplanetary Disk*, *ASP Conf. Ser.* 431, 407-431. [5] Schrader D and Lauretta D (2010) *Geochim. Cosmochim. Acta* 74:1719-1733 [6] Alpert S. P. et al. (2019) *QMA 2019*. [7] Bigolski J. et al. (2016) *Meteoritics & Planet. Sci.* 51: 235-260. [8] Kita N. T. et al. (2010) *Geochim. Cosmochim. Acta* 74:6610-6635.



**Fig. 1** (left) Normalized percentage of the most abundant mineral phases counted by the modal algorithm for OAs in Semarkona (AMNH #4128). **Fig. 2** (right) Elemental map (Fe-Ni-S; Red-green-blue) of OAs showing their structures and distribution of mineral phases (FeS is purple, Ni-rich phases green, Fe metal bright red, Fe oxide dull red).

