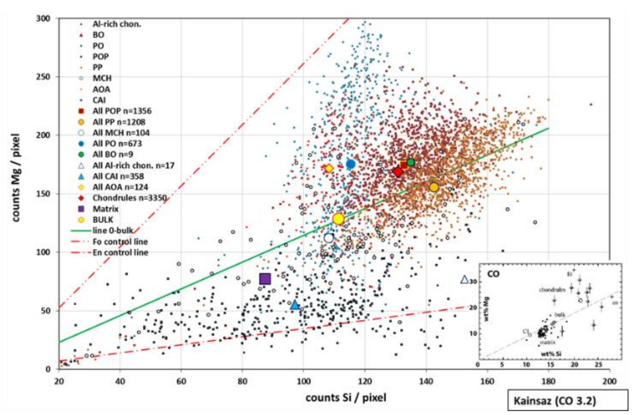
COMPLEMENTARY CO CHONDRULES & MATRIX APPROACH SOLAR MG/SI WITH GRADE.

D. S. Ebel[1,2,3], E. J. Crapster-Pregont[2,1], and M. K. Weisberg[43,1], [1]Dept. of Earth and Planetary Sci., American Museum of Natural History, New York, NY, 10024, USA (debel@amnh.org), [2]Dept. Earth and Environmental Sci., Columbia U., New York, NY, USA, [3]Earth and Environmental Sci., CUNY Graduate Center, New York, NY, 10016, USA. [4]Dept. Physical Sci., Kingsborough Community College, CUNY, Brooklyn, NY, 11235, USA.

Introduction: Recent work has established the complementary nature of major element compositions of chondrules and matrix in carbonaceous chondrites, particularly in Mg and Si [1]. Work by [1] on Kainsaz (CO 3.2) has been criticized by a claim [2] that the mean chondrule and matrix compositions of [1, their fig. 1; fig. left, below] are not resolvable from the line describing the solar ratio, on which bulk CO chondrite analyses fall. However, we have discovered clearly resolvable Mg/Si relationships among CO matrix and chondrules that vary systematically with petrologic grade. This finding clarifies the complementary relationship and renders the criticism by [2] moot.

Methods: In [3] we described methods of image analysis used to query every pixel in every outlined object in high resolution x-ray maps of chondrites, such that the per pixel abundances of elements were obtained for every chondrule and refractory inclusion, for all matrix pixels, and for the entire mapped area (i.e., the bulk). Samples of Colony (3.0, 33 mm^2, 2µm/pxl, Kainsaz (3.2, 46 mm^2, 2µm/pxl), Ornans (3.4, 14 mm^2, 1µm/pxl), Lancé (3.5, 46 mm^2, 3µm/pxl), and Warrenton (3.7, 14 mm^2, 2µm/pxl) [4] were mapped. Thus, more than 11 million pixels in Kainsaz were analyzed. Results provide significant statistical power to address element distributions.



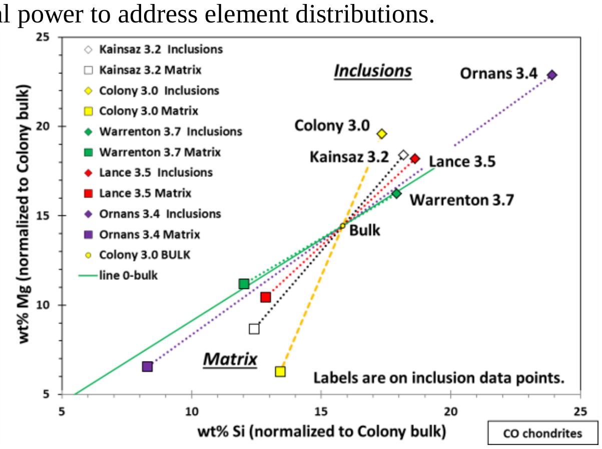


Fig. left: Per pixel counts of Si and Mg for all clasts, mean clasts, matrix, and bulk meteorite for Kainsaz [3]. Inset from [1]. Lines show Mg/Si count ratios from maps of enstatite and forsterite standards, normalized to conditions of Kainsaz analyses. **Fig. right:** Mg-Si relations in CO chondrites, with bulk analyses normalized to Colony bulk composition [7]. Mg/Si ratios approach solar (green line) with increasing petrologic grade (compare with Fig. 10 of [3]).

Results: The figure (left) shows Kainsaz Mg and Si counts/pixel values for 3350 chondrules and 482 refractory inclusions, the mean value for >11 million total pixels (bulk, yellow circle), and for matrix (37% of all pixels) [3]. Normalizing all the CO chondrites to the bulk Mg and Si compositions of Colony, the figure (right) shows the mean inclusion (chondrules and refractory inclusions) and matrix compositions for all five chondrites.

Conclusion: It is clear that the Mg/Si ratios in Colony (3.0) are most offset from the solar line (drawn through the CO bulk Mg/Si point). With increasing petrologic grade, the line segments joining matrix and chondrules rotate around the bulk point to coincide with bulk solar. One could even infer that at the highest grade (Warrenton, 3.7) the matrix and inclusions begin to move "inward" toward the bulk, as would be expected during equilibration. This finding confirms the well known, systematic metamorphic sequence of CO chondrites [6].

With the large populations of chondrules, refractory inclusions, and matrix pixels (e.g., 2215, 247 and $2.38x10^6$ in Colony) analyzed here [3], we are confident that the non-solar slopes of the line segments joining matrix and chondrules for least equilibrated CO chondrites in the right figure are meaningful. These results lend further weight to, and confirm, the conclusions reached by [1] in their pioneering study. Combined with recent evidence from Hf, W and Mo isotope studies, these results illustrate chondrule-matrix complementarity, which is an important constraint on astrophysical models of early nebular processes and the accretion of the earliest planetary building blocks.

References: [1] Hezel D. C. and Palme H. (2010) *Earth & Planetary Science Letters* 294, 85-93. [2] Zanda B. et al. (2018) Ch. 5 in *Chondrules*, eds. S. Russell & H. C. Connolly Jr. [3] Ebel D. S. et al. (2016) *Geochimica et Cosmochimica Acta* 172: 322-356. [4] Grossman J. N. and Brearley A. J. (2005) *Meteoritics & Planetary Science* 40: 87-122. [6] McSween H. Y. Jr. (1977) *Geochimica et Cosmochimica Acta* 41: 477-491. [7] Wasson J. T. & Kallemeyn G. W. (1988) *Philosophical Transactions of the Royal Society London* 325: 535-544. [8] Budde G. et al. (2016) *Earth & Planetary Science Letters* 454: 293-303.