TESTING CHONDRULE-MATRIX COMPLEMENTARITY: I. CO CHONDRITES. A. Patzer, E. S. Bullock, and C. M. O’D. Alexander, Carnegie Institution for Science, Department of Terrestrial Magnetism, 5241 Broad Branch Rd. NW, Washington, D.C., 20015 (apatzer@carnegiescience.edu).

**Introduction:** In terms of the origin and evolution of the major chondritic components (chondrules and matrix), two competing models have been proposed. One is the hypothesis of complementarity that is principally based on elemental ratios (Si/Mg, Fe/Mg, Ti/Al, Ca/Al), and the opposite trends thereof in chondrules and matrix. These trends are believed to reflect a genetic relationship, i.e., evaporation from chondrules and condensation into matrix [e.g., 1,2].

However, the fact that chondrules and the much finer-grained matrix must have remained coupled for perhaps millions of years before accretion into their chondritic parent bodies imposes severe constraints on how these components could have been stored in the disk. Also, presolar grains and organic C are present in roughly CI-like abundances in the matrices of the most primitive members of all chondrite groups [e.g., 3,4]. Neither presolar grains nor the organics would survive chondrule formation and would not reform after chondrule formation. Hence, one must appeal to a remarkable series of coincidences to produce their CI-like abundances, despite widely varying matrix-chondrule ratios. Furthermore, the matrix-normalized amounts of volatile elements, such as Zn, are roughly CI-like in all chondrite groups, except the enstatite chondrites [e.g., 5]. This would not be expected if volatile elements were lost from chondrules and redeposited in matrix.

Alternatively, it has been proposed that chondrules and matrix originally had CI-like composition and are not genetically related [6 and ref. therein]. The reported compositions of matrix in most chondrites are not CI-like, however [7]. To explain this, it has been suggested that chondrule matrices contain tens of percent of chondrule and refractory inclusion fragments [8] and/or that they were modified by chemical exchange during accretion and/or secondary parent body processes [9,10].

In order to further address this important debate, we have undertaken an extensive investigation designed to quantitatively determine in an unbiased way the proportions and bulk chemical compositions of chondrules, matrix and refractory inclusions in the most pristine carbonaceous chondrites (CCs). The method of choice is combined quantitative electron microprobe analysis (EPMA) and point counting of thin sections.

The first samples examined are the CO3.0 chondrites Dominion Range (DOM) 08006 and Allan Hills (ALH) 77307 as well as the ungrouped CO-CM-like Acfer 094 [11, 12, 13]. In addition to being highly primitive, their chondrule compositions are relatively small meaning that individual thin sections are likely to be representative of the bulk meteorites.

**Results:** A total of 3271, 3863, and 3398 points were analyzed on sections of DOM 08006, ALH 77307, and Acfer 094, respectively. At each point, a quantitative analysis was conducted and the point assigned to either chondrule, matrix, refractory inclusion (CAI or AOA), or isolated grain (silicate or opaque phase). Subsequently, the density of each point was estimated and the points in each category combined to estimate the mass fractions and average compositions of each component, as well as the bulk compositions of the sections. For the density correction, a suite of common phases was selected for each component with the aim to reproduce to 100 % the elemental abundances detected at each data point. In general, we were able to reproduce the vast majority of analysis totals to within 4 %.

In order to test the quality of our method, we compared our bulk elemental abundances for DOM 08006 with CO literature data [6]. Given our EPMA operating parameters (5 nA beam current at 15 kV, spot size of 3 µm, time-dependent ZAF correction) and the trace elemental detection limits related to those parameters, elements of potential concern include S, K, Na, Mn, P, Co, and Ti. The comparison revealed significant deviations for all of these elements except Ti.

**Discussion:** Sodium is depleted in DOM 08006, as well as in ALH 77307 measured by us and [1]. The low abundance can probably be attributed to Antarctic weathering, as can the depletion in S [14]. On the other hand, K, Mn, P, and Co turn out enriched due to larger enrichments in the matrix. Possibly, the EPMA standards we used and/or the data correction code we applied overestimate the abundances of these elements in a non-uniform medium like matrix.

Focusing on elements that are accurately determined with our method, we can now address the question of complementarity. As mentioned above, the main objective of our study is to determine with minimal bias the volume fractions and bulk compositions of individual chondritic components. Figure 1 shows Si- and CI-normalized concentrations of Mg and Al in those components. The normalized abundances of Mg in the bulk meteorites agree very well with CI and CO literature data (we observed the same agreement for the siderophile elements Fe and Ni). The bulk concentrations of Al, however, show some variation, in particular for ALH 77307. In order to explain the divergence, it is necessary to take a closer look at the contributing components.

First of all, chondrules and matrices of all three samples display rather poor matches with the available CO literature data. This could be due to actual compo-
tional variation owing to differences in sample selection and analytical techniques adopted in other studies. Based on our chondrule data for the two DOM 08006 sections, there may also be some compositional differences due to primary heterogeneities at the section scale and/or due to parent body and weathering processes. Only our data point for ALH 77307 matrix coincides quite well with the average literature value.

Fig. 1. Abundances of Mg and Al in components and bulk samples as determined in this study (solid red symbols; sil. gr. = isolated silicate grains), normalized to Si and CI composition [6]. Error bars are relative errors (1 σ) and usually not larger than the symbols. Literature data for CO chondrites (CO lit., open symbols) and ALH 77307 (ALH [matrix only], gray circles) are taken from [6, 16, 17, 18].

A prediction of the non-complementarity model of [6] is that chondrules and matrix should have CI-like Mg/Si and Al/Si ratios. The chondrules in DOM 08006 and Acfer 094 indeed agree well with CI (Fig. 1). The matrices in these two meteorites are relatively depleted in Mg, and in the case of DOM 08006 enriched in Al. In DOM 08006 matrix, CI and isolated silicate grains are roughly colinear. In cluster IDPs, it is only the inclusion of coarser grained olivines, pyroxenes, and sulfides that produces CI-like bulk compositions [15]. Thus, for DOM 08006, the non-CI matrix composition may simply be due to larger isolated grains not being included. Alternatively, the non-CI composition of DOM 08006 matrix could have been caused by the addition of chondrule mesostasis fragments to matrix, that are the complement to the coarser mafic phenocryst fragments in the isolated grains. Neither explanation works as well for Acfer 094 matrix, however.

In contrast to DOM 08006 and Acfer 094, the elemental signatures of the ALH 77307 components deviate from CI more significantly, showing strong fractionation of Al. ALH 77307 is slightly more altered/weathered than DOM 08006 and also contains more chondrules and inclusions with blurred boundaries that appear to be in a state of disintegration. A considerable number of these objects appear to have been relatively Ca- and Al-rich. Thus, there seems to have been more extensive chemical exchange with the matrix, particularly of Al and Ca-rich material.

**Summary:** We will present the most unbiased and comprehensive compositional data set for CO components available thus far. Our data support the hypothesis of CI-like starting material for both, chondrules and matrix. However, they also reveal that CO matrices have experienced additional preaccretionary and parent body alterations. The complementarity of chondrules and matrix is not required in order to explain the deviations from CI composition we observe.