COMPOSITION OF CHONDRULES AND THE ASSESSMENT OF CHONDRITIC ABUNDANCES: A PLANETARY PERSPECTIVE

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Introduction: Relative and absolute abundances of elements in chondritic materials provide the best guide to the compositions of initial starting materials in the solar system and for the modeling of bulk planetary compositions. We report here 159 analyses of 36 chondrules from ordinary (H, L, LL) and enstatite (EH, EL) chondrites. These data are used to assess variability of chondrule compositions and to gain insights into the variability in 'chondritic' ratios of refractory elements.

Oft times the prevailing perspective has been that more data and better analytical methods will lead to "better constraints" (i.e., more limited variation) in "chondritic ratios" of the refractory elements. Understandably Poisson counting statistics underpins a significant portion of this reasoning, given that a uniform reservoir will be better defined with one over the square root of n, where n represents the number of measurements. Historically, limited variation in chondritic ratios of the refractory elements has been the dominant paradigm. However, recently the degree of compositional variability far exceeds the variablility expected as a result of analytical methods (with post-formational disturbance not a factor), thus, we are now mapping out initial formational differences in chondritic ratios, particularly for the refractory elements (those whose half mass condensation temperatures are above ~1300 K *i.e.* a critical temperature reflecting the point above which one observes "limited" variation in the ratios). Observations of subtle variability in bulk chondritic samples shows there is a need to assess the variability in chondritic ratios of refractory elements (i.e., sub-10%, or perhaps sub-1%) within the component parts of these primitive meteorites.

Reports for the last decade have demonstrated that long-lived, time-integrated ratios of radiogenic isotopes (e.g., Re-Os, Sm-Nd, Lu-Hf, Th/U-Pb) record significant compositional variation in parent-daughter ratios for several refractory element pairs, demonstrating real and significant differences in these ratios between chondrite groups [1,2,3,4]. It is not uncommon, also that there is a clustering of compositions that is coincident with the redox-driven, petrological classification of chondrite groups (e.g., enstatite, ordinary, carbonaceous). The implications of this observation are many, but the origins of these phenomena are obscure.

Models for the bulk compositions of planets depend on several key factors and critical assumptions. The initial starting point is based on astronometric and geodetic observations of planets and the satellites. When possible, these data are complemented by additional physical data (e.g. magnetic, seismic, etc). A parallel constraint from cosmochemistry is derived from comparisons of the solar photosphere and compositional comparisons with constraints from chondritic ratios of the refractory elements.

Samples: In order to avoid potential complications from terrestrial weathering chondrules from falls were analysed. These include Bjurbole (L4), Tieschitz (H/L3), Chainpur (LL3), Kota-Kota (EH3) and Qingzhen (EH3) and Allende (CV3). Samples of highly metamorphosed EL5 and EL6 chondrites were also analyzed, but chondrules were barely recognizable, but the analysis of these samples were considered important as many of their bulk element ratios are significantly different from other chondrites, and ECs have been postulated to be potential terrestrial building blocks [5].

Method: Analyses were conducted using an integrated laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) with a large spot size.

Analyses were conducted with a Thermo Finnigan Element2 single-collector ICP-MS coupled to a New Wave frequency-quintupled Nd:YAG laser system (213 nm wavelength light). Measurements were carried out low-mass resolution, with 100 micron laser spot size and a fluence of ~2-3Jcm^{-2}. Signal optimization (based on ^{43}Ca and ^{232}Th spectra) and oxide production minimization (ThO/Th $\leq$ 0.12%) was used to maximize sensitivity and reduce isobaric interferences. The method used ^{43}Ca as the internal standard and a dwell time of 5 to 50 ms for isotope mass stations (depending upon element abundance).

Results: The relative variability in the absolute abundances of refractory elements and in element ratios [Figure 1] reflects differences in the raw materials used to build chondrules, as previously recognized [6]. The location and timing of chondrule formation remains to be resolved, but likely post-dates the formation of refractory inclusions (e.g., CAI), which are potential contributors to chrondrules. Such cannibalization processes will attenuate the inter-element fractionation patterns seen in CAI, and more iterations of the chondrules forming process experienced will cause the evolution of the chondrules to ever more chondritic compositions. The relative variability of refractory element abundances observed in these chondrules [Figure 2] is comparable to that seen in some high precision chondrite studies, if scales of material sampled are compared. The moderately refractory elements are

CI1 NORMALIZED CHONDRITIC RATIOS			
	average	±2 σ	RSD
Th/U	0.72	0.4	61%
Nb/Ta	1.17	0.6	54%
Lu/Hf	1.06	0.5	44%
Sm/Nd	1.04	0.4	35%
Zr/Hf	0.90	0.2	24%
Y/Ho	0.91	0.2	18%

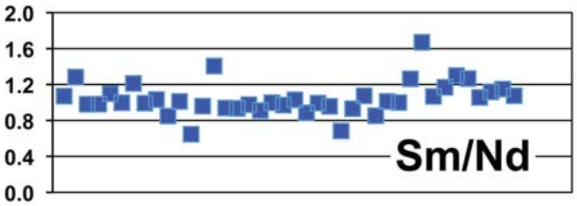

Fig. 1: *CI normalized data for refractory element ratio from 36 ordinary and enstatite chondrule, with the* <u>*range*</u> *in values given by the 2σ and RSD. The example for the Sm/Nd data set is shown graphically below with the y-axis being the normalized ratio data and the x-axis being an arbitrary sample order.*

more variable compared to the highly refractory elements.

We have not yet observed a clustering of compositions with respect to textural types, although the sampling is not sufficient to exclude correlations. The variable and low Th/U ratios observed are likely caused by U mobility. Element mobility processes likely contributed significantly to the highly variable characteristics of Sr, Ba, and Eu.

Conclusions: A preliminary observation from these data is that the modeling of bulk planetary composition, particularly for the absolute and relative abundances of the refractory elements, needs to take into consideration the variability. These chemical observations, in concert with that seen in various isotope systems, need to inform our models for planetary abundances of refractory element patterns.

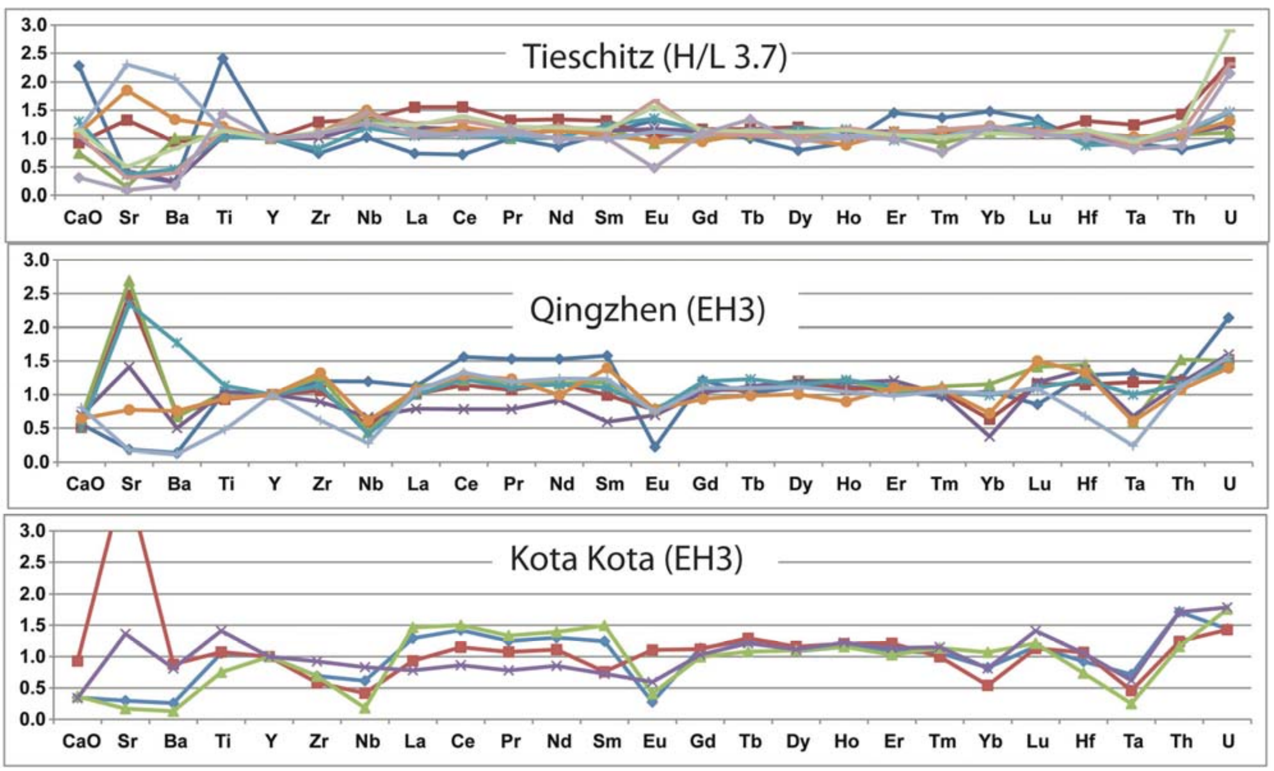

Fig. 2: *CI chondrite and Y-normalized abundances for refractory elements in ordinary and enstatite chondrules. Data for W are not shown as they show extreme variation and are likely affected by siderophile – lithophile fractionation effects as well as element mobility.*

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