TRACE ELEMENTS IN CI CHONDRITES: A HETEROGENEOUS DISTRIBUTION.

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Introduction: CI chondrites are regarded as the chemically most primitive rocks in the solar system. Their bulk composition is similar to that of the solar photosphere, except for some highly volatile elements, which are depleted [1]. Thus, the bulk elemental abundances of CI chondrites are used as the general reference composition in earth and planetary sciences. In detail, however, CI chondrites are regolith breccias, consisting of fragments up to several 100 μm in size, that are surrounded by a clastic matrix (Fig. 1). These fragments vary significantly in mineralogy and chemistry [2].

In the first part of this study the major element abundances of ~110 fragments were analyzed. They show considerable variation ([3]; Fig. 2). Clusters of fragments or lithologies with similar chemical and mineralogical characteristics could be defined [3].

In a next step, several important mineral constituents of CI chondrites were analyzed for their trace element contents: Phosphates, sulfates, and the phyllosilicate-rich groundmass.

Experimental: Scanning electron micro-scopy (SEM; JEOL 840A) was used to resolve the fine grained clastic textures of the four CI chondrites Orgueil, Ivuna, Alais, and Tonk. Fragments and single mineral phases can be easily distinguished in backscattered electron (BSE) images due to their different chemical compositions (Fig. 1).
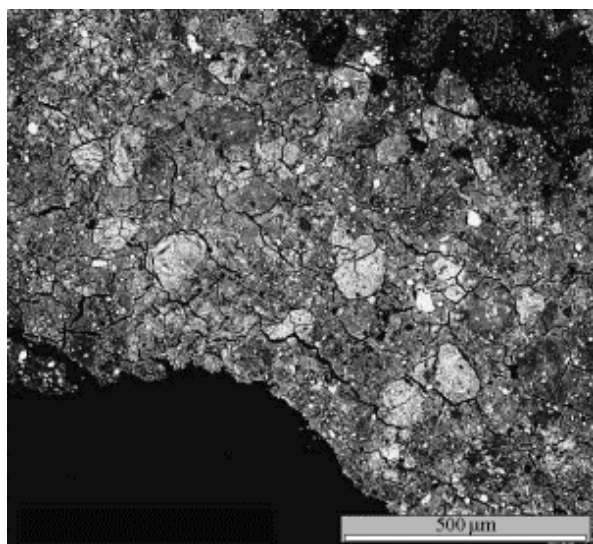

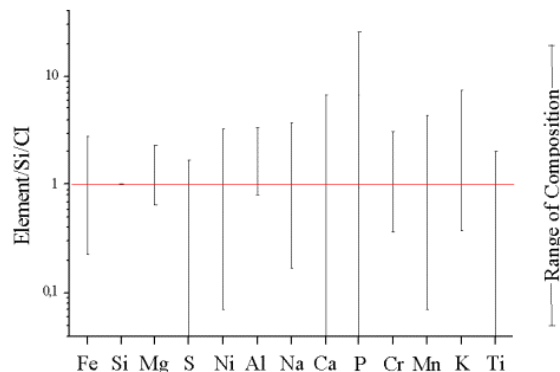Fig. 1: Brecciated area in the CI chondrite Orgueil (BSE image)

Fig. 2: Variation of major elements among ~110 fragments in CI chondrites.

Further information about elemental distribution was obtained with TOF-SIMS.

Following this documentation, analyses of trace elements in individual minerals were performed with the Washington University Cameca IMS 3F ionprobe.

Results: Preliminary REE data, normalized to CI abundances [1], are presented in Figs. 3-6. Since this reference standard is based on the bulk composition of CI chondrites, chemical deviations in mineral compositions of CI constituents can be nicely documented.

Phyllosilicate-rich Matrix: Matrix areas, which are mainly composed of phyllosilicates with small inclusions of other mineral phases, have REE abundances mostly below or close to CI. Values range from 0.15×CI for Eu to 1.1×CI for Tm (Fig. 3).

Phosphates: Since these minerals usually only occur as small single grains <<20 μm in size [2], or as aggregates of many small grains, contamination by surrounding matrix could not be avoided during trace element analysis. However, because of the huge differences in REE contents between phosphates and the phyllosilicate-rich matrix, contamination effects are insignificant. REE abundances in phosphates are relatively high, ranging from 26×CI for Lu to 150×CI for Yb (Figs. 4 and 5). In many cases (e.g., P32, P35; Fig. 5), HREEs are enriched compared to the LREEs, in contrast to phosphates in other chondrites, where LREEs are usually enriched [6]. A striking feature are the negative Gd anomalies found in about half of the phosphates (Fig. 4). It has been suggested that Gd hydroxide is more stable than hydroxides of the other REEs

[4]. Thus, one possibility is that Gd preferentially remained in solution during formation of the phosphates through aqueous alteration of CI meteorites. However, this fractionation mechanism is controversial [4] and cannot explain the existence of similar Gd anomalies in phosphates from H chondrites [6].

Sulfates: As was the case for phosphates, contamination with surrounding matrix also affected the measurements of the sulfates. The highest REE content was found for La (4.8×CI; Fig. 6). We can distinguish between two groups of sulfates: The first is slightly enriched in REEs above CI abundances, while the other has much lower abundances (Fig. 6). However, the strong correlation between the lanthanides and P indicates that most of the REEs probably reside in small phosphates that contaminated the analyses. Negative Gd-anomalies were found in two cases (S3, S14; Fig. 6).

Discussion: Since the phyllosilicate-rich matrix, which makes up most of the CI chondrites [2], and probably also the sulfates are, on average, depleted in the lanthanides compared to CI, phosphates – usually apatites - are needed to balance the REE budget. These could be small phosphates scattered throughout the matrix or concentrated in certain distinct phosphate-rich lithologies. Phosphate-rich lithologies do exist in CI-chondrites! They are characterized by very high abundances of phosphorus (P_2O_5 up to 18× CI). Since these lithologies are rare and non-uniformly distributed, lanthanides (and possibly other trace elements such as actinides [5]) are heterogeneously distributed in CI chondrites, at least on a sub-mm scale.

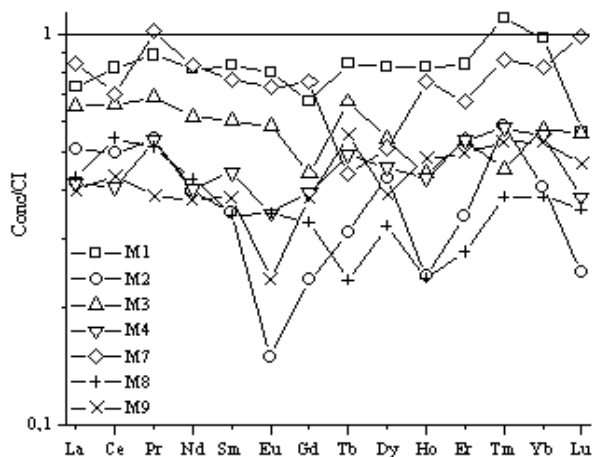**References:** [1] Anders E. and Grevesse N. (1989) *GCA, 53,* 197–214. [2] Endreß M. (1994), Ph.D. Thesis, University of Münster. [3] Morlok A. (2001) *MPS, 36-9 (Supp.),* A141. [4] Brookins, D. G. (1989), *Reviews in Mineralogy, 21,* 201-225. [5] Goreva, J.S. and Burnett, D.S. (2000) *MPS, 35-5 (Supp.),* A61. [6] Crozaz G. et al. (1989) *EPSL, 93,* 157-169
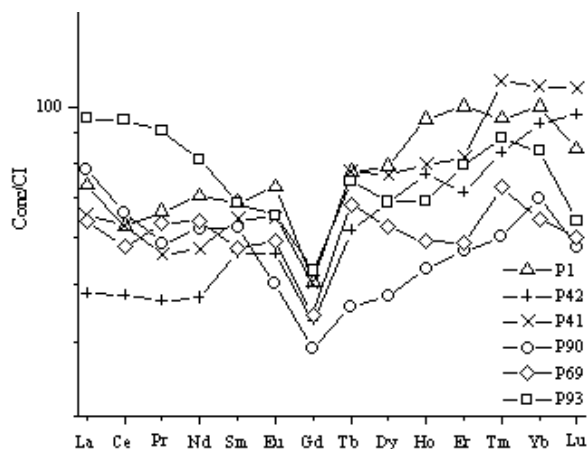

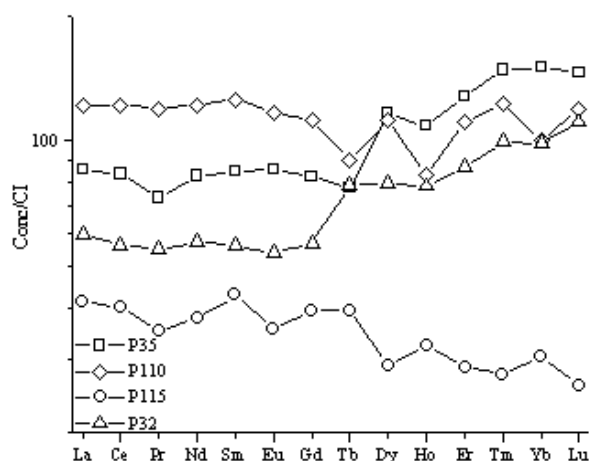Fig. 4: Rare earth elements in phosphates (1).

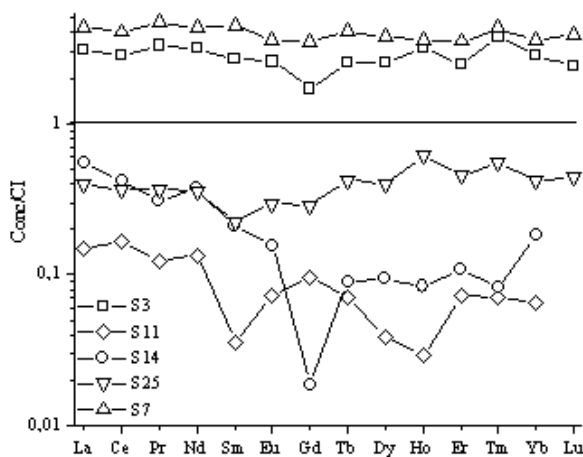Fig. 5: Rare earth elements in phosphates (2).

Fig. 3: Rare earth elements in matrix areas.

Fig. 6: Rare earth elements in sulfates.