THE CHEMICAL HETEROGENEITY OF CI CHONDrites.

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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, excluding some highly volatile elements, which are depleted [1]. Thus, the elemental abundances in bulk 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 [3]. The aim of the present study is to investigate the degree and extent of these heterogeneities.

Methods: Scanning electron microscopy (SEM; JEOL 840A) was used to resolve the fine grained clastic textures of the four CI chondrites Orgueil, Ivuna, Alais, and Tonk. From these chondrites eleven polished sections were prepared and mapped in detail by SEM. Fragments can be easily distinguished in back-scattered electron images due to their different chemical compositions (Figs. 1 to 3).

Major element concentrations of about 90 fragments, of several matrix areas and some bulk samples were obtained with a JEOL JXA-8600 S electron microprobe. Only silicate-rich fragments were investigated. Carbonate clasts that probably represent relics of former carbonate veins in the CI parent body (cf. Fig. 2 of [2]) were excluded from our study.

All electron microprobe data in this study were normalized to the sum of the corresponding calculated oxides according to their solar system abundances [1].

Additionally, element distributions of selected areas were mapped with time-of-flight secondary ion mass spectrometry (TOF-SIMS).

Results: We encountered considerable variations of the major element abundances among the ~90 fragments (Fig. 4). Concentrations of FeO range from 9.2 to 42.4 wt%, and of SiO2 from 14.2 to 43.8 wt%. Strong variations were also observed for MgO (7.8–25.8 wt%), NiO (0.2–3.3 wt%), and Al2O3 (1.0–4.3 wt%). Variations in SO3 and CaO are 0.9–15.8 wt% and <0.1–6.6 wt%, respectively. P2O5 is homogeneously distributed (0.1–0.8 wt%), except in some fragments with a high apatite abundance (1.2–5.2 wt%).

In other elements (in wt%): MnO 0.1–0.7, Cr2O3 0.2–0.7, and TiO2 <0.1–0.2. Unexpected results were obtained for Na2O (0.2 to 2.9 wt%) and K2O (<0.1 to 0.5 wt%): Na and K are highly enriched in many fragments of some polished sections and in a few fragments of other sections.

Our TOF-SIMS investigations revealed high F and Cl concentrations in two fragments. With this method, also indications for REE enrichments in phosphates were found.

Discussion: The element distribution in CI chondrites is highly heterogeneous. Considering individual fragments, some elements are highly enriched or depleted compared to their solar abundances [1]. With cluster analysis we defined several fragment groups with similar chemical and mineralogical characteristics, ranging from fragments dominated by coarse, Fe-poor phyllosilicates to fragments with high abundances of Fe (Fig. 1 to 3). These groups could be evidence for the presence of larger lithologies in the CI parent body, similar to those found for Ivuna [3].

The chemical variations are mainly correlated with specific mineral phases in the fragments. For example, Fe-rich fragments typically contain Fe-rich phyllosilicates, closely intergrown with ferrihydrite, and/or a high abundance of oxides and sulfides.

The Ca content mainly reflects the carbonate abundance. Concentration of P is strongly correlated with phosphate (apatite), which is highly unevenly distributed (Fig. 2). This also affects REE that are probably concentrated in phosphates.

Sulfates (Fig. 2) are the main carriers of S and probably of Na and K that are mainly correlated with sulfur.

Chemical heterogeneities within CI chondrites are probably based on the distribution of various lithic fragments in the breccias. Since individual fragments are small, these heterogeneities are restricted to the submilimeter scale. However, it was found that S, K, Na, and P (and probably the REE) show significant heterogeneities even on a larger scale.

Fig. 1. Backscattered electron image of a fragmented area in the CI chondrite Orgueil. The darker fragments are dominated by coarse, Fe-poor phyllosilicates, the brighter ones by Fe-rich phyllosilicates.

Fig. 2. Backscattered electron image of a large (~500×500 µm) phosphate-rich fragment from Orgueil. The bright fillings in the veins are sulfates. In the lower left edge below the fragment a bright, round aggregate of sulfides (including a large, single rectangular grain) is visible.

Fig. 3. Fe-rich fragment from the CI chondrite Orgueil (BSE image).

Fig. 4. Ternary diagram of the Fe, Si, Mg and Al contents in silicate-rich fragments from CI chondrites (circles). The solar system abundance [1] is marked with a cross.