

COMPLEMENTARY ELEMENT PATTERNS – IS THERE A GENETIC RELATIONSHIP BETWEEN CARBONACEOUS AND ENSTATITE CHONDRITES?

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Introduction: Thus far, “complementarity” has been described as a property of chondrules and matrix in a given meteorite to differ systematically in their composition, but in combination to have a bulk composition more closely resembling CI than either one does separately [1-3]. Here, we will discuss some features that can be seen in bulk chemical element patterns of carbonaceous and enstatite chondrites and point out an apparent “complementarity” between element patterns of two chondrite groups with very different petrographic characteristics. We came across this peculiarity while compiling a database with bulk chondrite analyses of PGE, Ni, Co, Au and Cr from the literature in order to further constrain geochemical criteria used for the identification of impactors [4].

The database: 806 analyses of 278 chondritic meteorites published over the past 40 years were gathered into a database [4]. The elements Os, Ir, Ru, Pt, Rh, Pd, Ni, Co, Au and Cr were chosen because they are most relevant for the identification of chondritic projectiles. The data were filtered and reduced based on element ratios, not only because element ratios can be determined more precisely than absolute values (“nugget effect”), but also because many datasets are incomplete (i.e., only selected elements were measured). Thus, simple averaging of absolute element abundances could lead to significant errors. The mean element concentrations of each chondrite group (used for the CI-normalized element patterns) were obtained by multiplying the respective element/Ir ratio with the mean Ir concentration of each group, since Ir was analyzed in most datasets. Here, we concentrate only on element patterns of carbonaceous chondrites rich in refractory inclusions (CO, CM, CV, and CK) and enstatite chondrites.

Carbonaceous chondrites: CI-normalized element patterns of CV, CK, CM, and CO chondrites (Fig.1) show a significant enrichment in ultrarefractory elements (Os, Ir, Ru), a feature that is probably related to the presence of refractory inclusions. However, the height of the patterns does not correlate with the relative abundances of refractory inclusions in the respective chondrites (according to [5]: CO = 13, CV = 10, CM = 5, CK = 4 vol.%) indicating that there are probably other components present that carry such elements as well. For example in CK chondrites, minerals enriched in PGE have been identified as another source of ultrarefractories [6].

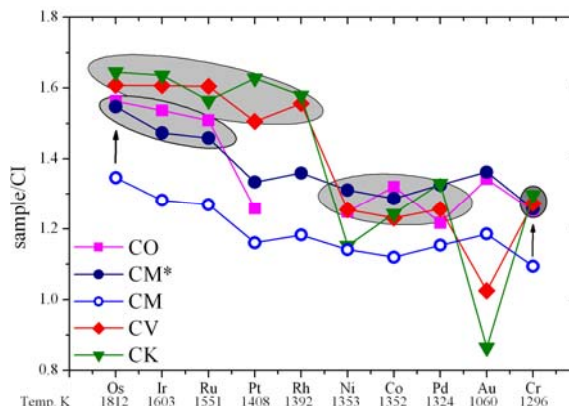


Fig. 1. CI-normalized concentrations of PGE, Ni, Co, Au and Cr in CV, CK, CM and CO chondrites. CM* = recalculated after subtracting 13 % H₂O content. Elements are plotted in order of decreasing condensation temperatures in the solar nebula [7]. Cr is plotted at the far right, because of its siderophile/lithophile character [7].

The relatively low element concentrations of CM chondrites compared to the other chondrite groups, are probably a result of the high H₂O-content of these chondrites, diluting the elemental abundances. Deducting ~13 % volatiles [8] from the original CM pattern (CM* in Fig. 1) yields not only a Cr abundance that is similar to the other chondrites shown, but also helps to demonstrate the close relationship between CO and CM chondrites versus CV and CK chondrites.

The element patterns of CO and CM chondrites decline after Ru to maintain a relatively flat pattern for all the remaining elements plotted, whereas CV and CK chondrites are still high in Pt and Rh before abundances decline (indicated by gray shading in Fig.1). Ni, Co and Pd have similar concentrations in all four groups, with the exception of Ni in CK chondrites - a depletion that is probably related to the oxidized nature of their mineral assemblages. CK and CV chondrites also show a strong depletion in Au, whereas CO and CM chondrites show a small Au enrichment. The Au depletion in CKs and CVs cannot be the result of terrestrial weathering as it is clearly present in data of the observed falls Karoonda (CK) and Allende (CV). Similarities in the element patterns probably indicate similar formation conditions (e.g., location or time of formation) for CV & CK versus CO & CM chondrites.

Enstatite chondrites: In contrast to the carbonaceous chondrites discussed above, enstatite chondrites

(Fig. 2) are rather enriched in the later condensing elements, especially Au. Despite the similarities in the element patterns of EH and EL chondrites, elements condensing after Rh have significantly different concentrations. The Cr abundances of EH and EL are similar, but lower than in all other chondrite groups as indicated by “Cr range” in Fig. 2, which demonstrates the narrow range of variation of this element.

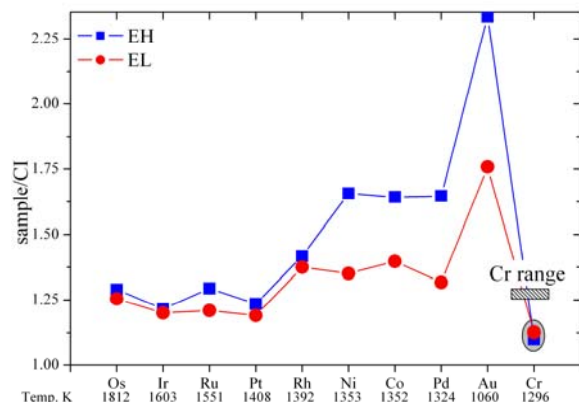


Fig. 2. CI-normalized concentrations of PGE, Ni, Co, Au and Cr in EH and EL chondrites. The Cr-values of EL and EH are lower than in all other chondrite groups (shown as “Cr range”).

Complementary element patterns: The composition of enstatite chondrites has been one of the most difficult to explain by nebular condensation models [e.g., 9,10] and, consequently, enstatite chondrite element patterns were considered erratic [5]. We would like to draw attention to the fact that element patterns of EH and CK chondrites display a remarkable complementarity (Fig. 3), which might be helpful evidence for constraining the formation conditions of both, enstatite chondrites as well as CK/CV chondrites.

The patterns in Figure 3 are nearly “mirror images” of each other. If one would average the concentrations of both groups, it would practically result in a flat line at ~ 1.45 times CI. We demonstrated for CM chondrites that it is useful to recalculate the element pattern taking their H_2O -content into account. If element abundances of CI chondrites would be recalculated in the same way, their values would be at least $\sim 20\%$ higher. When the patterns are normalized to these recalculated CI values, a virtual average of the two would be even closer to the CI composition (~ 1.2 times CI).

When suggesting a “genetic relationship” between enstatite and CV/CK chondrites, we intend to use the term like [3] to mean that these chondrites have either formed from a common source material, are products of the same process, or have exchanged material during their formation. The question is now, what are the

most likely processes that could leave such a characteristic imprint in bulk chondrite element patterns?

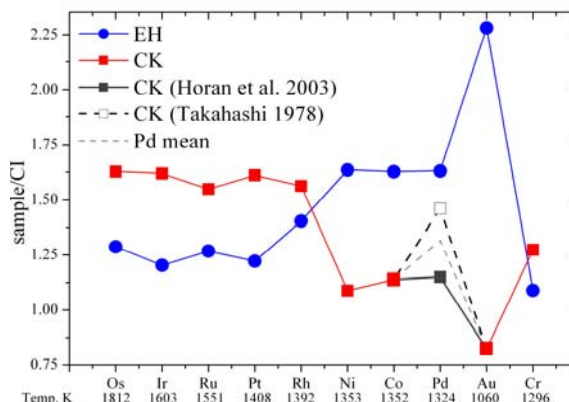


Fig. 3. CI-normalized concentrations of CK and EH chondrites. Note that the patterns are nearly mirror images of each other. The only data available for Pd concentrations in CK chondrites are from [11] and [12]. The more recent data make the element patterns even more complementary.

Were ultrarefractory elements removed with high-temperature condensates from the source region of enstatite chondrites as suggested by [9,13] and added to the formation region of CK and CV chondrites? Could the process that led to the much debated depletion of moderately volatiles in CV (and CK) chondrites also have led to their enrichment in enstatite chondrites? Is this process related to the redox state of enstatite chondrites (reduced) versus CV/CK chondrites (oxidized)? So far, we are not able to answer these questions as we are primarily presenting our observations from the database, but we are looking forward to compelling discussions at the meeting.

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