

A COMPOSITIONAL STUDY OF WHOLE-ROCK FRAGMENTS OF THE L6 CHONDRITE BRUDERHEIM. Johnson R. Haas, and Larry A. Haskin, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130

Anomalous concentrations of La, Ce, and Nd were reported for six 300-800 mg whole-rock chips of the Bruderheim chondrite analyzed by RNAA [1,2]. To check these results and to measure compositional heterogeneity of an ordinary chondrite, we have analyzed twenty, 100-120 mg, interior whole-rock chips of the L6 equilibrated chondrite Bruderheim by INAA. We observed significant variations in the concentrations and relative abundances of the REE and other elements, but not of the type previously reported [1,2]; we tentatively conclude that those arose from sample contamination.

For the 20 samples, max/min concentrations are as follows: Eu, Na, and Ir, 1.8 - 2.1; Sc, Cr, Fe, and Ni, 2.1 - 2.5; Au, 3; Yb and Lu, 3.5; La, 6.8; Co, 7.4. Excluding unusually metal-rich sample BH89-5, max/min concentrations are as follows: Na, Sc, Fe, Ir, 1.3-1.5; Cr, Eu, Ni, Se, 1.7-1.9; Au, 2.2; Yb, Lu, 3.4-3.5; Co, 3.8; La, 4.0; Sm, 4.5. Max/min values for concentration ratios (excluding BH89-5) are as follows: Ni/Au, 1.3; Ni/Ir 1.6; Ni/Co, 2.2; La/Yb, 1.5; Cr/Sc, 1.8; La/Eu, 2.4. Siderophile-element concentrations for BH89-5 fall slightly outside and lithophile-element concentrations fall within the range for the other fragments.

REE concentrations, normalized to the average for all 20 chips, are shown in Fig. 1. Negative and positive Eu anomalies arise from variations in relative proportions of plagioclase and phosphate minerals. Apparent Lu anomalies are common, but fall within the range of analytical uncertainty. Compositional variations are so large that samples ranging from 3.2 g (Na₂O) to 135 g (Co) would be needed to give values accurate to $\leq 2\%$ σ_s for most elements. Mean relative REE abundances (Fig. 2) differ from the mean values for CCl chondrites (3).

Using a least-squares chemical mixing model, we find that the compositional variations among the fragments for the elements we determined can be accounted for quantitatively as resulting from different proportions of homogeneous end members that correspond to known mineral phases in the meteorite. These end members and their diagnostic elements are as follows: olivine and orthopyroxene (premixed, no diagnostic element); clinopyroxene, Sc; plagioclase, Na and Eu; kamacite, Co/Ni; taenite, Co/Ni; troilite, Se; chromite, Cr; and Ca-phosphate (premixed merrillite + apatite), REE. End-member compositions lie within the range of published values for phases in L5 and L6 chondrites.

Ranges of end-member proportions (wt %) (excluding BH89-5) are as follows: olivine + orthopyroxene, 64-72%; clinopyroxene, 2.3-6.2%; plagioclase, 7.4-10.9%; kamacite, 3.1-17%; taenite, 2.4-4.4%; troilite, 4.9-10.0%; chromite, 0.53-1.1%; phosphate, 0.10-0.8%; total, 99.1 - 101.5%. The quality of the fits to the observed concentrations was very good. Predicted and observed concentrations differ by <1% for Sc, Cr, Fe, Co, Ni, and Se, and by <3 σ_s for other elements (except two Na, one Lu, and one Au values), with most ≤ 1 σ_s analytical uncertainty. End member proportions summed to $1.00 \pm .01$ for 19 of the fragments. Model estimates of uncertainties in the sums are large (up to 10%); this is because constraints on proportions of olivine and orthopyroxene are insufficient; these proportions arise from the mass balance for Fe, Ni, Co, and Sc.

In the course of the modeling study, we determined the effect of analytical uncertainty on the quality of fit. In a Monte-Carlo study, we generated 20 pseudo-analyses of a hypothetical fragment consisting of a perfect linear combination of end members and having the same composition as the average of the actual fragments. These analyses included a computed random analytical error for each element in each of the 20 pseudo-analyses. The analytical errors we initially assumed were based on our customary reported uncertainties (i.e., our estimates of overall analytical accuracy). The resulting pseudo-analyses, when tested with the mixing model, produced fits of much poorer quality (e.g., errors in sums exceeding 10%) compared with the fits obtained for 19 fragments using actual analytical data. They also produced a substantial range of mineral proportions for the original single composition.

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We then repeated the Monte Carlo experiment using estimates of *relative* precision (i.e., only the *uncorrelated* uncertainties encountered in the analysis of a single fragment) in place of estimates of overall accuracy. The uncertainties in the end-member proportions for the hypothetical single composition for this Monte Carlo model were comparable in magnitude to those found for the actual chips and the range of compositions was very small. The larger uncertainties used initially destroyed the elemental ratios crucial to accurate determination of end-member proportions. Thus, the mixing model, applied to the data for the 19 fragments, correctly reflects the differences in end-member proportions from chip to chip, but only because the sizes of the uncorrelated uncertainties in the analytical data are small for most elements.

We conclude that the mixing model accounts quantitatively for the compositions of the fragments (except BH89-5) and that most fragments consist of equilibrated minerals in differing proportions, as expected. We also note that compositions of 100 mg chips differ substantially from each other, and to an extent that indicates substantial compositional variations among samples of several grams in size. The amount of material required to provide a good average analysis is excessive (~100 g for Co). More useful information is obtained by analyzing several small fragments than a split of a very large, homogenized one.

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(1) Allen, R.O. (1970) PhD dissertation, U. Wis.-Msn. (2) Haskin, Helmke, Paster, & Allen (1971), in *Activation An. in Geochim. & Cosmochim.* (Brunfelt and Steinner, eds.), 201, Oslo U. Press. (3) Anders & Ebihara (1984) *Geochim. Cosmochim. Acta* 53, 197.

Fig. 1. REE concentrations of individual chips of the Bruderheim chondrite normalized to the average for all 20 chips.

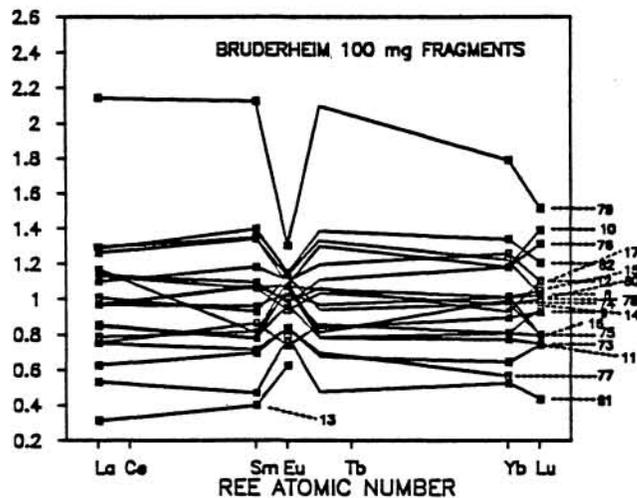


Fig. 2. The average REE concentrations for the 20 chips normalized to the C1 values of Anders and Ebihara (1984).

