Meteorite and Materials Analysis: X-ray Microprobe Studies

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Introduction

Iron meteorites are iron-nickel alloys with significant trace element concentrations. They present analytical challenges very similar to those of synthetic metal alloys and other modern materials, in that similar textural and compositional problems must be unraveled in order to understand the minute (often at the ppm level) compositional changes that greatly influence the properties of the alloy. Analyses of iron meteorites and metal alloys thus require very similar technologies.

The current taxonomy and classification of iron meteorites [1] are based mainly on the textures that are determined by the major elements (Fe and Ni) and on accurate quantitative analysis of taxonometric elements, especially Ga and Ge. The x-ray microprobe, like the electron microprobe, offers researchers an opportunity to determine the spatial distribution of the elements and so assess homogeneity. The x-ray microprobe also enables the determination of the chemical speciation and local structural environment for these species (see below).

Results

Here we present data obtained on a Canyon Diablo (CD) meteorite specimen by using the PNC-CAT 20-ID microprobe. Bulk analyses of CD by other workers had shown Ga content to be about 80 ppm and Ge content to be about 320 ppm [1]. We first mapped the distribution of Ni, Ga, Ge (and Fe) (Fig. 1) by using a 5-µm spot size at an excitation energy of 11 keV. The distribution patterns of Ga and Ge are, as expected, governed by the major element distributions. However, in addition, there are a few localized areas of micrometer dimension with high concentrations of these trace elements ("hot spots"), commonly at phase boundaries. First, it can be ascertained from the Fe/Ni intensity ratios that the Ni concentration in the matrix is approximately 7%, confirming the known mineral (phase) kamacite. A diagonal trace of the concentration profile across one of the squares is shown in Fig 2. The transition regions between the phases or features are relatively sharp. A more finely focused examination would be of interest.

The x-ray absorption spectra (XAS) for each of the four mapped elements were measured in selected areas. These measurements provided both the edge and extended x-ray absorption fine structure (EXAFS) collected out to approximately k = 16. The x-ray absorption near-edge structure (XANES) data indicate that all elements have an essentially metallic character, as might be expected.

The EXAFS analysis for *each* mapped element shows that the Fe lattice has a bcc structure, characteristic of kamacite, and that Ni, Ge, and Ga are located in bcc sites surrounded by Fe. The EXAFS analysis was done with WinXAS and by calculating model radial profiles with FEFF7 [2]. The structures were modeled as a cluster of eight bbc unit cells, and radial curves were calculated for the three nearest neighbors of the atom in the center.

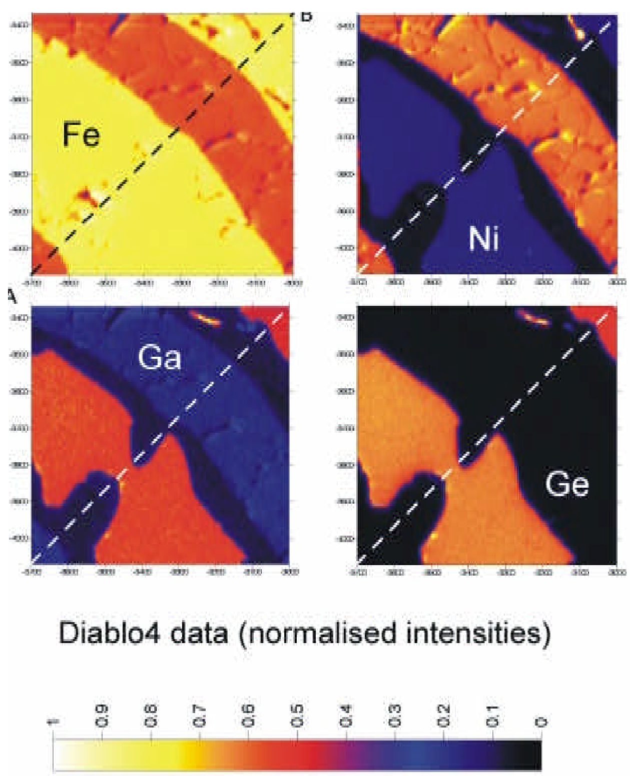

FIG. 1. Element distribution map of Fe, Ni, Ge, and Ga in a section of the CD meteorite specimen. The boxes are approximately 300 µm^2. Lighter colors represent higher intensities.

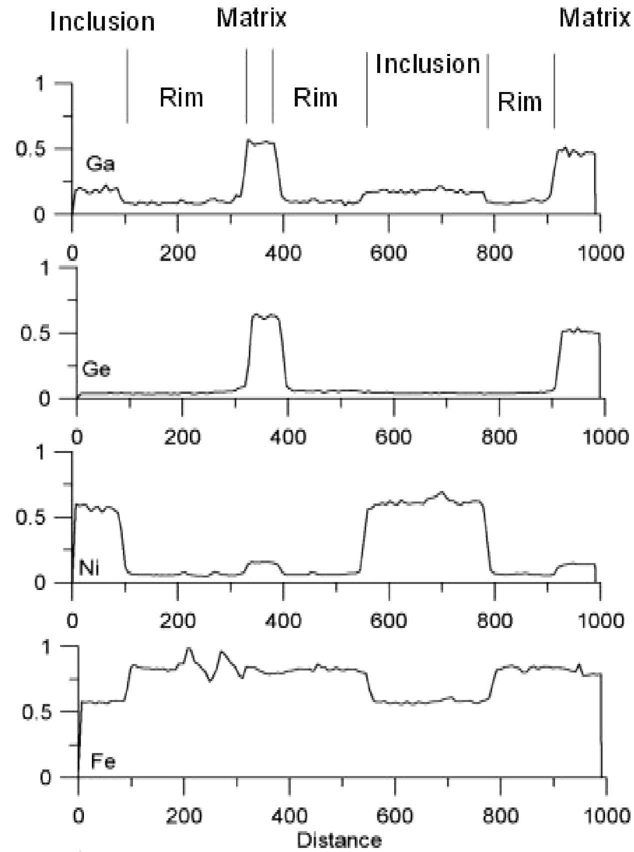

FIG. 2. Normalized concentration profiles along the diagonal of the CD box in Fig. 1. The structures are labeled "matrix" (high-Fe area), "inclusion" (thick red area in upper left box), and "rim." The irregularities in the Fe profile are surface irregularities, which can be seen in the Fe picture.

EXAFS oscillations were Fourier transformed in the k-space range of 2.5-9.5 $Å^{-1}$. Inverse transforms of the first two peaks were taken over a range of 1.0 to 3.7 Å. The experimental and simulated radial profiles are compared for the case of Ge in Fig. 3. Ni and Ga results are similar. A more detailed analysis of different regions of the sample is in progress.

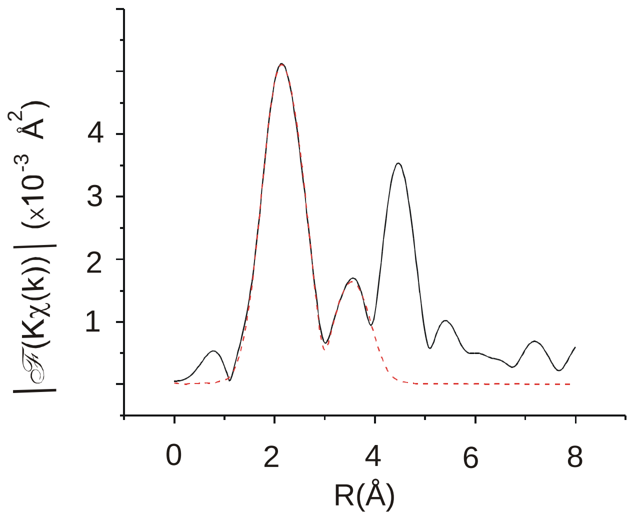

FIG. 3. Fit of the experimental Ge radial distribution in the Fe matrix of a bcc structure to the simulated curve for the first two peaks representing the three nearest neighbors to Ge in the structure.

Acknowledgments

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References

[1] V. F. Buchwald, *Handbook of Iron Meteorites*, Vols. 1 and 2, *Iron Meteorites* (University of California Press, Berkeley, CA, 1975).

[2] S. I. Zabinsky, J. J. Rehr, A. Ankudinov, R. C. Albers, and M. J. Eller, Phys. Rev. B **52**, 2995 (1995)