IRON AND NICKEL ISOTOPIC FRACTIONATION ACROSS METAL GRAINS FROM THREE CB_b METEORITES.
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Introduction: We report iron and nickel isotope measurements along profiles across zoned metal grains from three CB_b meteorites (Queen Alexandra Range 94411 (QUE), Hammadah al Hambra 237 (HaH), and Mac Alpine Hills 02675 (MAC) that bear on the question of the origin of these metal grains. CB meteorites are a small group of primitive metal-rich (60-70% metal) meteorites of which the CB_b are a subgroup characterized by a larger fraction of metal (~70%) with many, but not all, the metal grains being zoned with nickel enriched by a factor of about two in their cores and more or less chondritic Fe/Ni at the rims [1]. The CB meteorites are important in that they may provide distinctive insights into processes that operated during the earliest stages of the solar nebula. However, their origin and the nature of these processes is still uncertain. On the one hand the zoned metal grains have been interpreted as being equilibrium or non-equilibrium condensates of nebular origin [1,2], while on the other hand, it has been argued that the young formation ages of the CB chondtrites along with their mineralogical and chemical characteristics are inconsistent with a nebular setting but suggest an origin of the CB meteorites by large protoplanetary impacts [3]. The only prior work we are aware of involving both Fe and Ni isotopic fractionation in CB_b metal grains is an abstract [4] reporting Fe and Ni isotopic differences of about 8‰ per amu between the isotopically light cores and heavy rims of metal grains from HaH. A second abstract [5] reported a detailed Fe isotopic fractionation profile across a metal grain from HaH with Fe in the Ni-rich core being light by about 2.5‰/amu compared to the rim. Both these earlier studies argued for a condensation origin for the zoned metal grains involving kinetic isotope fractionation during non-equilibrium partial condensation from a nebular gas.

We were motivated by these earlier studies to expanded the search for Fe and Ni isotopic fractionation in zoned metal grains from CB_b meteorites to include multiple grains from not only HaH 237, but also from QUE 94411 and MAC 02675. The persuasiveness of generalizations about the origin of zoned metal grains in CBb meteorites based on their Fe and Ni isotopic zoning will depend on the degree of correspondence between the isotopic fractionation of multiple grains from different CB_b meteorites.

Samples and Analytical Methods: Backscattered electron images of centimeter-size sections of the CB_b meteorites QUE 94411, HaH 237, and MAC 02675 were used to identify the metal grains, and Fe and Ni atomic abundance profiles were measured across a subset of these using the JEOL JSM-5800LV SEM equipped with an Oxford Link ISIS-300 energy-dispersive microanalytical system at the University of Chicago. Three Fe-Ni zoned grains from each of the meteorites were selected for Fe and Ni isotopic analysis. Iron and Ni isotopes were measured using the Cameca ims 1280 ion microprobe at the University of Hawaii using ~60 pA O^- primary ion beam focused to ~10 μm and a mass resolving power of ~8000 (M/ΔM). Because we are interested in isotopic zoning across the grains, the data are normalized to the isotope ratios at the centers of the grains and are reported in ‰/amu relative to the central values.

Results: Profiles of Ni abundance in atom% and Fe and Ni isotopic fractionations in ‰/amu with 2σ error bars are shown in Figure 1 for a typical metal grain from each of the three CB_b meteorites. The other profiles we measured across the metal grains from each meteorite are very similar to those shown for that meteorite in Figure 1. Note that the isotopic fractionation of Fe and Ni is very similar in the case of the grains from HaH and MAC. However, QUE shows poorly defined fractionation profiles and for the example shown Fe may be heavier rather than lighter in the core of the grain. Table 1 summarizes the data for all the grains for which Fe and Ni isotopes were measured, showing that HaH and MAC have very similar isotopic fractionations of about 4‰/amu, while the isotopic fractionations of the QUE grains are not resolvably different from zero.

Discussion: The Fe and Ni isotopic fractionation we measured in the HaH grains (~4‰/amu) is about half that of previously reported values [4] and comparable in the case of Fe isotope fractionation to the largest value reported by [5]. The three grains we measured from MAC are very similar in isotopic fractionation to the HaH grains, but the QUE grains, while similar to all the other grains in terms of Ni zoning, are distinctly different in their isotope fractionation.

The isotopic zoning of HaH 237 and, by analogy that of MAC 02675, has been used as evidence of kineitic fractionation during condensation [4,5]. However, diffusion-limited evaporation of Fe and Ni would produce similar isotopic fractionations with isotopically heavy rims. The key evidence that evaporation was not a significant process is that for Ni, being less volatile than Fe, evaportion would result in Ni increasing from core to rim, which opposite from what is observed.

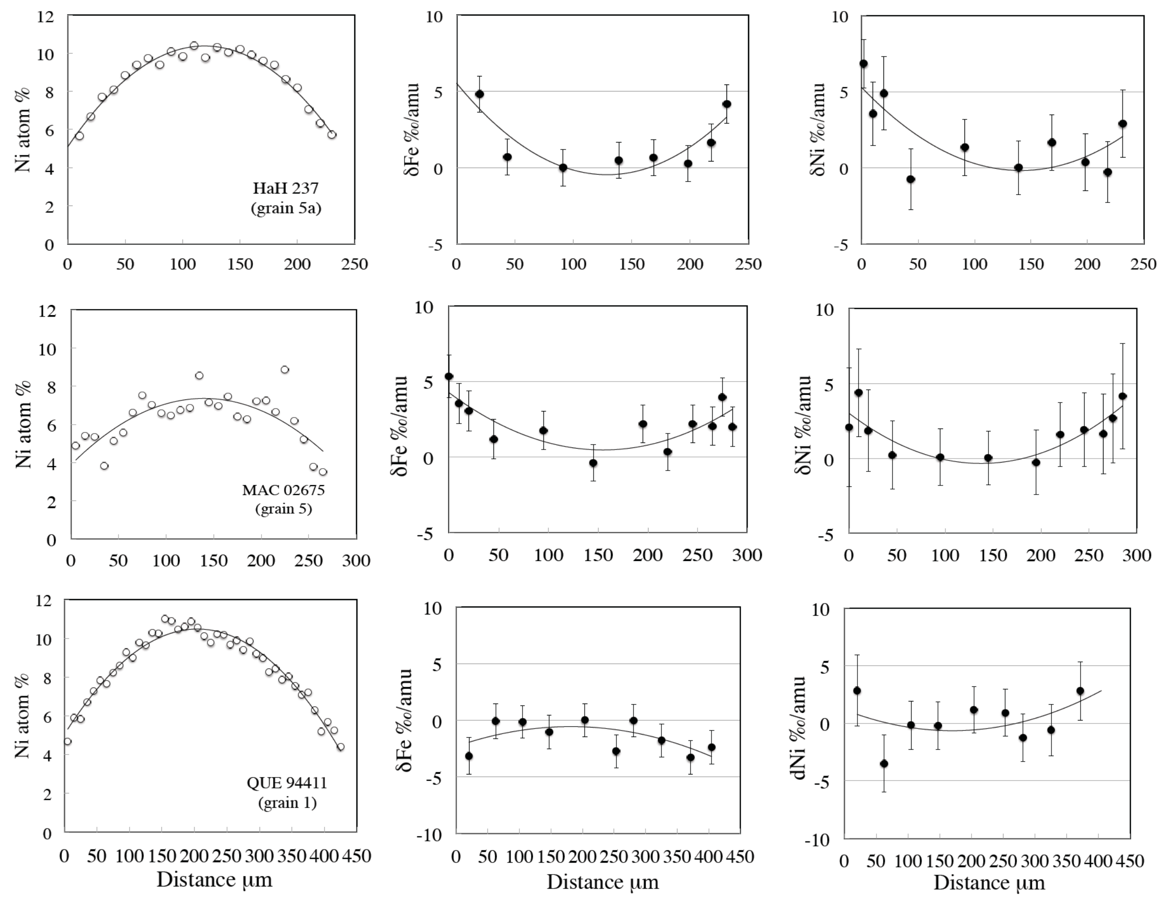

Figure 1. Zoned metal grains from HaH 237, MAC 02675, and QUE 94411. The thin lines in the figures are second order fits that do not have a theoretical basis. All distance scales in µm.

Table 1

Meteorite	*Grains*	*D Ni atom % (core-rim)*	*dFe ‰/amu (core vs. rim)*	*dNi ‰/amu (core vs. rim)*
HaH 237	3	5.5±0.5	-4±1	-5±1
MAC 02675	3	4.5±0.5	-4±1	-4±1
QUE 94411	3	6.0±1.0	+0.5±1	-1±1

It follows that kinetic isotope fractionation by non-equilibrium condensation was most likey involved in the formation of the metal grains, but even this raises several issues, specifically the large magnitude of the isotopic fractionations in HaH 237 and MAC 02675 and the lack of such fractionation in the grains from QUE. Kinetic isotope fractionation during condensation will depend on the inverse square root of the isotope reduced masses $\mu_i = m_i M / (m_i + M)$, which involves both the isotope mass m_i and the mean atomic weight M of the total gas (see [6] for experiments showing how reduced mass determines isotope fractionation by diffusion in gases). Thus the large isotope fractionations in the HaH and MAC grains would require that Fe and Ni condensed from a gas of relatively high mean molecular weight (M~40, perhaps an impact plume as proposed by [3] but certainly not a nebular gas of solar composition). The lack of fractionation of the QUE grains could be explained by condensation from a gas of low mean molecular weight (M<5) such as a H-dominated nebular gas.

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