PLATINUM GROUP ELEMENT DISTRIBUTIONS IN BENCUBBINITE METAL GRAINS.

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Introduction: Recently it has been demonstrated that some metal grains in CH chondrites and the bencubbinites QUE94411 and Hammadah al Hamra 237 display compositionally zoned concentration profiles that are interpreted to originate by condensation from a gas of solar composition [1]. It has been estimated that these grains grew on a timescale of days [1]. The persistence of these profiles, and the lack of kamacite/taenite phase exsolution, indicates further that these grains have not undergone significant thermal processing (>300 ˚C) since their formation. Here we report spatially resolved trace element concentration measurements in metal grains in the bencubbinite QUE94411, for the platinum group elements (PGEs: Ru, Rh, Pd, Os, Ir, Pt) and other siderophiles. The siderophile element profiles measured in these grains are compared to models of the condensation process to elucidate possible grain growth processes at high temperatures in the solar nebula.

Experimental: The thick section QUE94411,6 was X-ray mapped in Ni $K\alpha$ using an electron microprobe. Large (>100 μm) chemically zoned and unzoned metal grains were selected for trace element microanalysis by laser ablation ICP-MS. Prior to laser ablation the P, Cr, Fe, Co, and Ni compositional profiles of these grains were measured by electron microprobe.

A CETAC LSX-200 laser ablation peripheral was used for solid sample introduction into a magnetic sector ICP mass spectrometer, the Finnigan Element™ [2]. Each point on the sample was analyzed with 30-pulse laser bursts; the laser-ablated pit produced was approximately 30 μm in diameter and 15 μm deep. A series of analyses were performed across each grain in ~30 μm steps. The isotopes monitored were ^{31}P, ^{51}V, ^{53}Cr, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{95}Mo, ^{101}Ru, ^{103}Rh, ^{105}Pd, ^{182}W, ^{185}Re, ^{192}Os, ^{193}Ir, ^{195}Pt. Instrumental sensitivity factors for each isotope were determined by measuring signal intensity from the ataxite Hoba, which has known concentrations of the elements of interest [3]. Precision of the LA-ICP-MS measurements was typically 10% (1σ).

Results and Discussion: Figure 1 shows siderophile element profiles across a representative zoned FeNi metal grain in QUE94411. The data in this figure are normalized to Fe and CI abundances [4]. As shown, those siderophiles that are more refractory than Fe display a radial gradient in this grain that mimics that of Ni and Co.

The PGEs (with the exception of Pd) are present at maximum normalized concentrations of two to four times that of CI chondrites; this enrichment diminishes toward the rims of the grain, where the abundance is
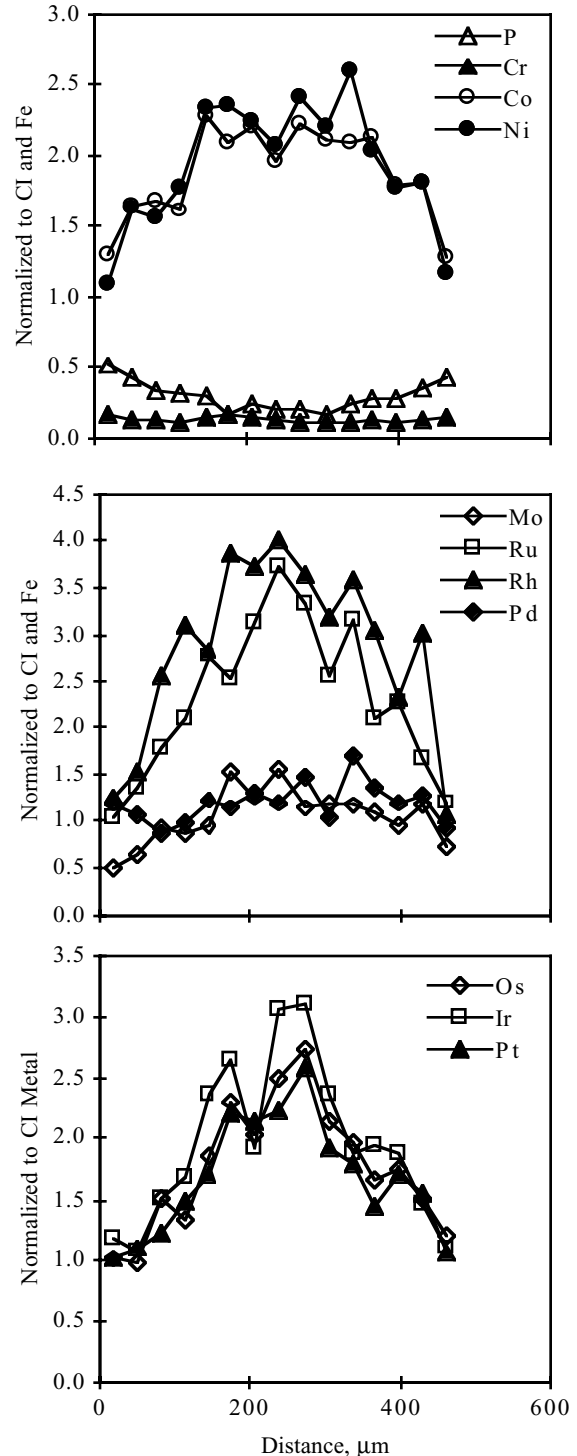

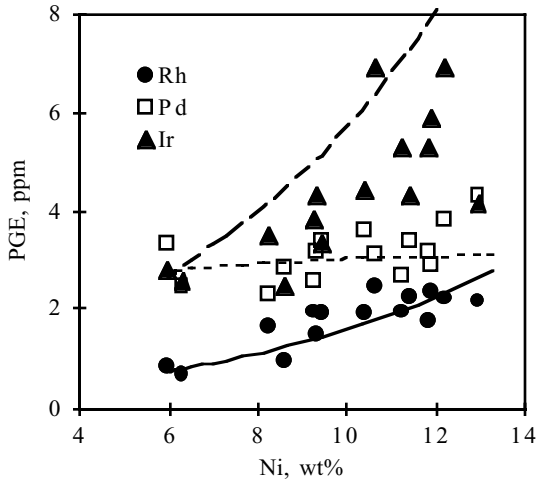Figure 1. LA-ICP-MS profiles across a zoned metal grain in QUE94411.

Figure 2. PGE content vs Ni in the metal grain from Figure 1. Symbols: LA-ICP-MS data; lines: calculated path of equilibrium condensation.

approximately chondritic. Pd has a volatility similar to that of Fe, and shows no enrichment in the grain interiors. Likewise, Cr and P are more volatile than Fe and show profiles complementary to the refractory elements in Figure 1; Cr and P are enriched at the edges of the grain and relatively depleted in the interiors. Mo shows a maximum in the interior of the grain and diminishes toward the rim, but is uniformly lower in CI-normalized abundance than other refractory metals; this is interpreted as evidence of condensation under conditions that are more oxidizing than a gas of solar composition.

Equilibrium thermodynamic calculations were used to predict the composition of a condensed metal alloy in equilibrium with a solar gas over a range of temperatures at 10 Pa. The formalism of Fegley and Palme [5] was used, with f_{O2} values adopted from Ebel and Grossman [6]. These calculations, spanning temperatures of 1360 K (high Ni) to 1285 K (low Ni), are compared to the LA-ICP-MS data in Figure 2. Rh, Pd, and Ir are shown for illustrative purposes; data on other PGEs show behavior similar to one of these. Pd varies only slightly with Ni content, consistent with the data from the grain in Figure 1; this reflects the fact that Pd has a volatility similar to that of Fe. Rh varies by more than a factor of 2 over this temperature range; the concordance between the LA-ICP-MS data and the model is very strong for Rh as well as for Ru. As also seen in Figure 2, the calculated and observed Ir vs. Ni curves from the grain approximately match, although there is a small, systematic discrepancy with the measured values of Ir lower than the calculated abundance by 20-30%. Os and Pt show similar behavior to Ir. Of the seven zoned grains studied so far in QUE94411, the grain in Figure 2 exhibits the highest levels of depletion of Os, Ir, and Pt; several grains show no such depletions at all.

Figure 2 illustrates that the range of compositions preserved in the zoned metal grains of QUE94411 approximately match the trajectory of compositions described by an alloy in equilibrium with a cooling gas of solar composition. It is important to note, furthermore, the absence of a reservoir effect recorded in these grains. At 1360 K and 10 Pa, 100% of the Ru, Rh, Os, Ir, and Pt should reside in the condensed phase; therefore, one would expect a spike in PGE compositions (except Pd) at the center of each metal grain, with negligible PGE content elswhere. The sequestering of refractory elements in the cores of the metal grains was apparently not sufficient to produce a refractory-poor gas, from which the remainder of the grain would have condensed. On the contrary, each radial zone of the growing grain has a composition suggesting equilibrium between the outer, growing shell and an unfractionated solar gas composition. The absence of a reservoir effect implies that the growing metal grains contain only a small fraction of the PGE budget; hence the gas must have remained supersaturated during grain growth. Cooling rates of about 0.2 K/hr have been inferred from kinetic constraints on the formation of these grains in a nebula of 10 Pa pressure [1]. At this rate our models of fractional condensation project that sufficient supersaturation of refractory PGEs in the cooling nebula could have been produced if the number of nuclei was limited to $\sim10^{-2}$ m^{-3}.

An implication of the inferred supersaturation of PGEs in the nebula is that these elements must not have fully condensed from the gas to form PGE-rich nuggets at high temperatures [6]. Kinetic barriers to condensation of these highly rarefied elements may have prohibited the formation of such grains.

An alternative model that we have considered to generate the radial composition gradients in refractory siderophiles is one in which an originally high and uniform PGE content is altered by diffusion into the surrounding environment. Refractory element enriched grains would have formed during the condensation process, and then diffusion could take place in the parent body. Later disruption of the parent body surface would allow rapid cooling and account for the observed brecciation of the meteorite. Although inter-grain profiles in QUE94411 do not indicate that diffusion occurred between grains that currently coexist, this does not exclude diffusion from the metal grains into the matrix that surrounded them prior to brecciation.

References: [1] Meibom A. et al. (1999) *JGR, 104,* 22053-22059; Weisberg M. et al. (1999) *LPSC XXX,* #1416; Meibom A. et al. (2000) this volume. [2] Campbell A. J. and Humayun M. (1999) *Anal. Chem., 71,* 939-946. [3] Campbell A. J. and. Humayun M (1999) *LPSC XXX,* #1974. [4] Anders E. and Grevesse N. (1989) *GCA, 53,* 197-214. [5] Fegley B. and Palme H. (1985) *EPSL, 72,* 311-326. [6] Ebel D. and Grossman L. (1999) *GCA,* in press. [6] Palme H. and Wlotzka F. (1976) *EPSL, 33,* 45-60.