

**ORIGIN AND THERMAL HISTORY OF FeNi-METAL IN PRIMITIVE CHONDRITES.** A. J. Campbell<sup>1</sup>, M. I. Petaev<sup>2</sup>, A. Meibom<sup>3</sup>, C. Perron<sup>4</sup>, and B. Zanda<sup>4,5</sup>, <sup>1</sup>Dept. of the Geophysical Sciences, University of Chicago (5734 S. Ellis Ave., Chicago, IL 60637 USA; a-campbell@uchicago.edu), <sup>2</sup>Dept. of Earth and Planetary Sciences, Harvard University (20 Oxford St., Cambridge, MA 02138 USA; mpetaev@cfa.harvard.edu), <sup>3</sup>Dept. of Geological and Environmental Sciences, Stanford University (Building 320, Lomita Mall, Stanford, CA 94305 USA; meibom@pangea.stanford.edu), <sup>4</sup>Laboratoire d'Etude de la Matière Extraterrestre, Museum National d'Histoire Naturelle (61 rue Buffon, 75005 Paris, France; perron@mnhn.fr), <sup>5</sup>Dept. of Geological Sciences, Rutgers University (610 Taylor Rd., Piscataway, NJ 08854 USA; zandahe@rci.rutgers.edu).

**Introduction:** FeNi metal is commonly a major component in primitive chondrites, and is therefore a potentially important and useful constituent for investigating the high temperature history of chondritic components. In part, this is because of the mineralogical simplicity, relative to silicate systems, that metal exhibits at high temperatures in the range of compositions that are appropriate to chondrites. This reduced number of phases allows one to more easily interpret chemical variations in metal in terms of its thermal and chemical history. In addition, the siderophile elements span a wide range of chemical behaviors, so that analysis of an appropriate suite of siderophiles often can be employed to eliminate or confirm hypotheses regarding the more complex microstructures of the Fe-Ni system at low temperatures makes it also a very sensitive indicator of secondary thermal processes.

In the last few years there have been several important developments that have enhanced our understanding particularly of the high-temperature history of primitive chondrite metal. The first of these is the enormous increase in the number of specimens that has resulted from the systematic searches for meteorites, especially in Antarctica and the Sahara desert. Concomitant with the increase in number of meteorites available for study is a better recognition of the diversity among them; hence our classification schemes have improved, and the number of classes expanded. Several primitive chondrite groups, including the CR, CH, and CB classes, which are metal-rich, consist of a small number of quite rare meteorites, and were largely unrecognized until a number of their members were recovered from the Antarctic and the Sahara.

Another recent development that has facilitated insight into primitive chondrite metal is the improvement in microanalytical techniques that are sensitive to siderophile elements at trace abundance levels. Laser ablation ICP-MS has been particularly successful in this regard. This technique has been used to provide trace siderophile element analyses at spatial scales down to 15  $\mu\text{m}$ , which allows a new way of approaching problems regarding chemical and thermal history of meteoritic metal, that is complementary to the much longer history of trace

element analysis of lithophile elements by ion microprobe.

Finally, experimental studies continue to provide valuable support for, or tests of, proposed metal-forming processes. Recent experimental efforts have focussed particularly on better understanding the consequences of redox reactions, evaporation, and diffusion on the compositions and textures of primitive chondrite metal.

**CH and CB Chondrites:** These meteorites contain a variety of metal textures, and have attracted much recent attention in both analytical and theoretical studies [1,2]. The CH chondrites, and the CB<sub>b</sub> chondrites QUE 94411 and HH 237, contain zoned metal grains that have been interpreted as products of nebular condensation [3,4,5]. These interpretations are based on the zoning of minor elements (Ni, Co, Cr, P, Si) as well as trace elements (PGEs, Re, Au, Cu, Ga), and are supported by isotopic mass fractionations in Fe, Ni, and Cu [6]. The refractory elements (relative to Fe) are enriched in the cores of the zoned metal grains relative to the rims, whereas elements more volatile than Fe are depleted, but often less depleted toward the rims. Comparisons of the observed compositional zoning to calculations of metal condensation, grain growth, and diffusion have been used to constrain the high-temperature thermal history and timescales of formation of these grains [3,4,5,7]. The unzoned metal in CH and CB<sub>b</sub> meteorites also exhibits significant compositional variation, and trace element studies suggest that this metal formed under varying conditions of temperature and oxygen fugacity [7,8]. The origin of metal in Bencubbin and related CB<sub>a</sub> members remains uncertain, but seems to be different from that of the zoned grains of CH and CB<sub>b</sub> chondrites. The coexistence of metals of different origins in the same chondrites or chondrite groups is not the least puzzling characteristics of these meteorites.

**CAI Metal:** CAIs are generally enriched in refractory siderophiles, to levels similar to their refractory lithophile enrichments, indicating a high-temperature origin for both components. Low

temperature processes, including sulfidation and oxidation of the metal, has partly obscured the original compositions of CAI metal, at least in CV chondrites [9]. However, the distribution and relative abundances of trace siderophile elements indicate that not all of the variations in metal composition can be attributed to secondary processing. CAI metal reflects incomplete mixing of metal precursors that had a wide range of temperatures of formation [10,11]. The distributions of Mo and W in CV CAIs have been interpreted as evidence of relatively high oxygen fugacity conditions [10,12], in sharp contrast to the highly reducing conditions inferred from  $Ti^{3+}/Ti^{4+}$  ratios and other indicators in the silicate phases [13]. There is a relative paucity of studies of CAI metal from chondrite classes other than CV.

**CR Chondrite Metal:** Renazzo and the other CR chondrites are unequilibrated and highly reduced, and offer excellent opportunity to study the relationship between metal and silicate evolution in chondrites. The formation of metal in CR chondrites was intimately connected with the chondrule-forming process [14]. The observed range of chondrule textures indicates that metal was expelled, usually incompletely, from the chondrule interiors. Variations in minor and trace element compositions in metal, between interior grains and grains on chondrule rims, serve as evidence that volatile loss during heating was followed by recondensation of volatile siderophile elements into the rim metal [15,16]. Redox effects are also observed in CR chondrule metal; these are possibly related to exchange between metal and silicate, and transport of oxidizable elements from interior metal to the vapor phase [14]. The bulk depletion of volatile siderophile elements from Renazzo chondrules may have been inherited from their precursors [15,16].

**Ordinary Chondrite Metal:** The chemistry of most ordinary chondrite metal is dominated by parent body low-temperature processing, specifically sulfidation and kamacite/taenite equilibration. Nonetheless, some pre-accretionary history may be preserved in the least equilibrated specimens. As in the CR chondrites, it is evident from textural features and composition relationships between metal and silicates that the chondrule-forming process played an important role in ordinary chondrite metal evolution.

**Experiments:** Recent studies continue to yield interesting insights into chondrite metal chemistry. Some work has followed the trail of [17], pursuing possible redox mechanisms for metal formation in chondrules. Heating of a CI composition under a range of  $P(H_2)$  conditions showed that Fe metal

formation occurred primarily by FeS desulfidation, and not by FeO reduction under the experimental conditions [18]. However, TEM studies of experimentally produced dusty olivines indicate that in situ FeO reduction may have occurred [19]. Other studies have emphasized transport properties in the metal, to better elucidate the distributions of siderophiles and the timescales associated with observed diffusion [20,21]. These results, and the relative paucity of experimental efforts, suggest that greater emphasis on experimental strategies to understanding high-temperature processing of chondrite metal may prove rewarding.

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