ELEMENTAL AND STRUCTURAL DIVERSITY IN NORTON COUNTY METAL NODULES

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Introduction: The Norton County aubrite is a brecciated pyroxenite formed under highly reducing conditions [1]. It is dominated by low-Fe silicates, with lesser metals, sulfides, phosphides, and other phases. Under these conditions, elements that are normally lithophile, such as Ti, Ca, and Na, become chalcophile. Metallic Fe-Ni is a minor component and occurs in a range of petrographic relationships from sub-micron to cm-sized nodules [2]. Proposed origins of the metal are several including, formation through in-situ reduction, extraneous incorporation, fragments of fractionally crystallized core, or trapped metal from a silicate+metal+sulfide magma [2]. Based in part on trace-element data, [2] concluded that the metal did not undergo fractional crystallization in a core; instead it is an incompletely segregated fraction formed during partial melting. Lyul' et al. [3] proposed different histories for matrix and metal nodules, though with genetic links between them. They suggest that matrix metal is derived from partial melting of the nodules, which were the primary metal of the parent planetesimal. As such, they further propose that the elemental variations between the nodules was controlled by element redistribution between metal and silicate during metamorphism of the aubrite parent body.

Despite extensive geochemical work, there is little correlative study between metal structures, distribution and types of precipitates, and elemental data. In addition, distinguishing characteristics between "matrix metal" and "nodules" is poorly constrained. Here is presented structural and elemental data from six Norton County "nodules", with the view of revealing metal structures that correlate with specific formation histories.

Norton County metal nodules: A magnet was passed over 74 g of Norton County material; 0.2 g adhered to the magnet. The six largest nodules (NC1 to 6), which are all similarly sized, were cut in half. One half from each was embedded in one resin mount. The sample was polished, etched briefly in nital, and washed in methanol. NC1 to 5 are roughly equant, with longest dimension ~1 mm, whereas NC6 is 3 mm long and <0.5 mm wide. Each polished metal face presents roughly the same surface area. The sample was viewed with optical and SEM imaging. Elemental data were measured by WDS with a JEOL JXA-8530F Hyperprobe in the LeRoy Eyring Center for Solid State Science at ASU.

Results and discussion: Each nodule shows a distinct pattern of precipitates and metal compositions and structures. Kamacite free of visible precipitates shows a relatively narrow range of Ni, but more variable Si and Co (Table 1). No taenite was found, though tetrataenite inclusions occur in NC5. Ni-Fe silicides occur in NC2, 3, 5, and 6. Perryite, with variable Si:P ratios, and containing C, are abundant as micron- and sub-micron laths in NC3, 5, and 6. NC5 contains a diverse suite of precipitates, including caswellsilverite, Ti-rich troilite, tetrataenite, Cr-sulfide, and SiO_2. A "crack" in the grain contains SiO_2, Cr-sulfide, and Ti-rich troilite. Schreibersite occurs as precipitates in NC1 and adhering grains in NC4 and 6. Precipitates of Cu-Zn are sparsely distributed in NC2 and 6.

Table 1. Nodule kamacite compositions determined by WDS. Each point was measured from areas free of visible precipitates.

Nodule	Si (wt%)	Ni (wt%)	Co (wt%)	Ni/Co
NC1 (8*)	0.02±0.01	5.45±0.19	0.51±0.02	10.7
NC2 (7)	0.52±0.07	5.44±0.41	0.48±0.02	11.3
NC3 (6)	0.31±0.03	5.36±0.26	0.52±0.03	10.3
NC4 (6)	0.25±0.03	5.09±0.08	0.41±0.02	12.4
NC5 (8)	b.d.l.	4.50±0.05	1.03±0.08	4.4
NC6 (6)	0.31±0.01	5.00±0.31	0.44±0.01	11.4

*number of analyses. b.d.l. – below detection limit

Perryite shows three orientations across NC2,3,4, and 6, suggesting that each nodule is a single kamacite crystal. It is well-developed in NC2 forming a pseudo-Widmanstätten pattern, with three prominent sets of lamellae that sub-divide the metal into larger trapezoidal regions. These regions show a precipitate-free rim and core with precipitates. Neumann bands are weakly developed in several of the nodules. For example, in NC3, the Neumann bands show a boudinage texture, with the pinched regions occupied by cross-cutting silicide laths. Nodule NC1 is composed of several dominant kamacite grains, as revealed by the orientations of the Neumann bandss.

The range of structures and compositions are consistent with metals of diverse histories. The non-chondritic Ni/Co ratios of the Si-poor nodules NC1 and 5, are consistent with an origin distinct from the Si-rich nodules (NC2,3,4,6). Their low Si contents suggest that they did not form on the aubrite parent body through melting or segregation of metal with bulk compositions consistent with those that condensed under the highly reduced conditions that formed the Si-rich metal of enstatite chondrites. This study demonstrates the utility of metal compositions and precipitates as tracers of early Solar System processes.

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