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SIDEROPHILE ELEMENTS IN METAL FROM METAL-RICH ANGRITE NWA 2999. M. Humayun[1], A. J. Irving[2] and S. M. Kuehner[2], [1]National High Magnetic Field Laboratory & Dept. of the Geological Sciences, Florida State University, 1800 E. Paul Dirac Drive, Tallahassee, FL 32310, USA (humayun@magnet.fsu.edu), [2]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA 98195.

Introduction: The angrites are an important class of differentiated meteorites, mainly ultramafic rocks, the number of which has grown to over eleven with recent finds from Antarctica and hot deserts [1, 2]. The major chemical characteristics of the angrites include a refractory element enriched, volatile element depleted, oxidized composition. Based on alkali element abundances (e.g., K/La~10^{-3}xCI [3, 4]) the angrites are the most extremely depleted meteorite or planetary samples known. Paradoxically, volatile siderophile (e.g., Ge) and chalcophile elements are notably higher in angrites than the alkalis [4, 5]. These chemical characteristics, and oxygen isotopes, distinguish angrites from Martian meteorites and HED achondrites [4]. Some chemical features of angrites were noted to be similar to those of group IVB irons, and a common asteroidal origin of both groups has been proposed [6], although a candidate asteroid is not known. The discovery of a third metamorphosed angrite, NWA 2999, with symplectite and corona features led to the proposal that the large planetary size required may imply an origin from Mercury [1, 7]. Despite their relatively oxidized nature, 10 out of the 11 angrites contain metallic Fe-Ni alloy (<2%), but the presence of about 10% coarse Fe-Ni metal in NWA 2999 reported by [7] led to an attempt to examine the proposed link between group IVB irons and angrites in this meteorite.

Samples and analytical methods: NWA 2999 is a metamorphosed and formerly brecciated igneous rock and, except for its anomalously high metal content, has textural and mineralogical similarities to Angra dos Reis and LEW 86010 [7]. A polished thick section of NWA 2999 studied by electron microprobe [7] was used for siderophile element analysis by laser ablation ICP-MS. A New Wave UP213 laser ablation system coupled to a Thermo Finnigan Element™ in the Plasma Analytical Facility of the National High Magnetic Field Laboratory was used for the analyses [8]. Metal grains were selected using the reflected light microscope on the UP213. The peaks ^{25}Mg, ^{31}P, ^{34}S, ^{53}Cr, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{69}Ga, ^{74}Ge, ^{75}As, ^{95}Mo, ^{102}Ru, ^{105}Pd, ^{182}W, ^{185}Re, ^{192}Os, ^{193}Ir, ^{195}Pt and ^{197}Au were determined in low resolution mode (R=300). A spot size of 40 or 55 µm with 7-10 s dwell time was used for NWA 2999 metal, and 100 µm tracks or area raster were used for the standards. Relative sensitivity factors were obtained from the standards NIST SRM 1263a (P, S, Cr, Fe, Co, Ni, Mo), North Chile (Filomena, IIAB: Cu, Ga, Ge, As, W, Au) and Hoba (IVB: Ru, Pd, Re, Os, Ir, Pt). Concentrations were obtained by normalizing to Fe+Co+Ni=100%.

Results: Sixteen individual metal grains and 1 silicate grain were analyzed for siderophile elements. The metals grains have 4.9-10.7% Ni, and chondritic relative abundances of most highly siderophile elements (HSE: Ru, Pd, Re, Os, Ir, Pt, Au). The silicate grain (calculated as Fe+Co+Ni=100%) had 0.5% Ni and extremely low values of most HSE (e.g. <0.03 ppm Ir).

The abundances of many elements (W, Ga, Cr, P, Cu, Re, Mo) in NWA 2999 metal may have been affected by metamorphic equilibration between metal and silicate. The metal was depleted in P, Cr, Cu and Ga, but mainly exhibited enrichment in W. Correlations between Re and other HSE were poor indicating Re disturbance. Correlations between Mo and other HSE were good, with about half the grains showing positive enrichments in Mo/Ir (1.5-3xCI). The correlation between Ni and HSE was weak, and most grains had Ni depletions relative to Pd, implying that the abundances of Fe and Ni may also have been subject to metamorphic disturbance. Figure 1 is a plot of the most immobile elements. The metal grains exhibit chondritic

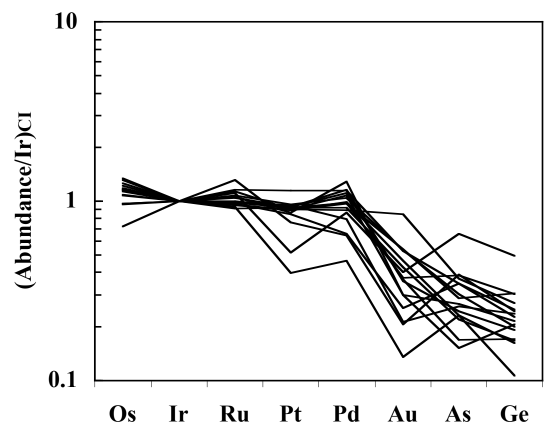

Figure 1: Ir- and CI-normalized abundance pattern for selected siderophile elements in NWA 2999 metal.

relative abundances of Os, Ir, Ru, Pt and Pd with moderate depletion of the volatile elements Au, As and Ge (Fig. 1). Notably, Pd/Ir ratios are chondritic but Au/Ir (0.3xCI) and Ge/Ir (0.2xCI) ratios are lower than in any of the major chondrite types.

Discussion: The individual metal grains have compositional features that lead us to believe that they are exogenous to the angrite silicate lithology. The chondritic relative abundances of all the highly siderophile elements (excluding Re) seen in Fig. 1 imply a chondritic origin of the metal. All iron meteorite classes exhibit fractionated HSE patterns, since Pd is incompatible, while Os, Ir, Ru and Pt are compatible in solid metal relative to liquid metal [9]. Particularly, the group IVB irons exhibit a strongly fractionated HSE pattern with $(Pd/Ir)_{CI}$=0.27 [6]. Group IVB irons also have the most extreme depletion of moderately volatile elements: $(Au/Ir)_{CI}$= 0.015, and $(Ge/Ir)_{CI}$= $3.6x10^{-5}$. In contrast, the metal grains in NWA 2999 are high in Au, As, and Ge, and exhibit a chondritic Pd/Ir ratio. Thus, this metal has no compositional relationship to group IVB irons. Compositionally, the metal shares none of the refractory element, volatile element or redox characteristics of the angrite silicate lithology, either. We conclude, therefore, that the metal grains in NWA 2999 must have been introduced during brecciation of the angrite parent body surface, implying that this angrite was an ancient regolith breccia.

The metal grains do not match any of the major chondrite types in terms of bulk composition. The level of volatile element depletion in the main chondrite classes is shown in Figure 2. The metal grains in NWA 2999 have lower volatile element abundances than any

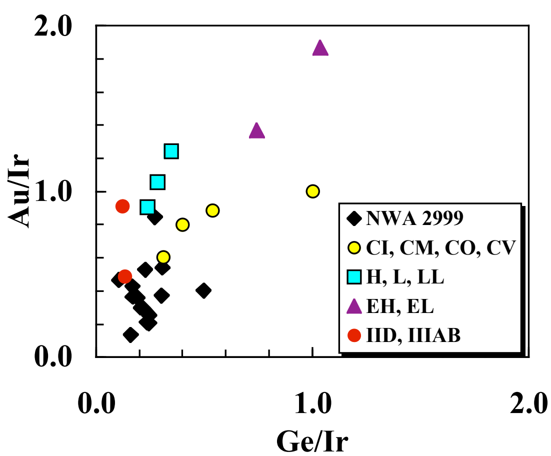

Figure 2: Volatile element abundances in major chondrite types, NWA 2999 metal and group IID, IIIAB iron meteorite parental liquids.

of the major chondrite types. The parental magma compositions estimated for group IID and IIIAB irons [10] are also shown for comparison. Both iron groups have similar $(Ge/Ir)_{CI}$, but can be distinguished by group IIIAB having higher $(Au/Ir)_{CI}$. The IID parental liquid composition overlaps the NWA 2999 metal in Fig. 2. A more detailed comparison of metal compositions must include Pd abundances, currently not available for IID irons. One possibility is that metal in NWA 2999 was originally derived from an ancient chondritic impactor class for which samples may not be present in our meteorite collections. However, the oxygen isotopic composition of NWA 2999 ($\Delta^{17}O$= -0.08 ‰, [1]) constrains any such impactor to have an oxygen isotope composition close to the Terrestrial Fractionation Line.

An important implication of this study is that the moderately volatile siderophile element content of NWA 2999 is influenced by the presence of exogenous metal introduced by impact processes. By extension, the high levels of moderately volatile siderophile elements observed in other angrites [4, 5] may also have been introduced during brecciation and, therefore, carry limited information on the intrinsic composition of the silicate lithology. If this is true, the low intrinsic volatile and siderophile element compositions of angrites would make it possible to identify the impactor compositions bombarding the angrite parent body (possibly Mercury), in a similar manner to assessments made for the Moon [11]. The potential exists for the identification of distinct (multiple) impactors among the growing numbers of angrites.

The presence of exogenous metal in NWA 2999, and possibly in other angrites, has important ramifications for isotopic systematics involving siderophile elements, including ^{60}Fe-^{60}Ni and ^{182}Hf-^{182}W, and possibly ^{53}Mn-^{53}Cr systematics. Of the 16 metal grains analyzed in NWA 2999, 2 grains exhibited $(W/Ir)_{CI}$ <0.4, and six grains exhibited $(W/Ir)_{CI}$ >2, implying exchange of W between metal and silicate during metamorphism. Likewise, the $(Cr/Ni)_{CI}$ ratio of 0.1-5.3 $x10^{-3}$ implies nearly complete loss of exogenous Cr to the NWA 2999 silicates.

References:

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