DIVERSE METALS AND SULFIDES IN POLYMICT UREILITES EET 83309 AND EET 87720.

J. S. Herrin[1], D. W. Mittlefehldt[1], H. Downes[2], M. Humayun[3], [1]NASA/Johnson Space Center , Houston, TX, USA (jason.s.herrin1@jsc.nasa.gov), [2]School of Earth Sciences, Birkbeck, University of London, Malet St. London, WC1E 7HX, UK, [3]National High Magnetic Field Laboratory and Dept. of Geological Sciences, Florida State University, Tallahassee, FL 32310, USA.

Introduction: Ureilites are a group of carbon-bearing ultramafic achondrites. The majority of samples are monomict with major and trace element compositions consistent with a restitic origin after extensive loss of basaltic melts and significant loss of their metallic component during anatexis. Monomict ureilites are thought to represent largely intact samples of the ureilite parent body (UPB) mantle. Polymict ureilites, by contrast, are fragmental breccias consisting of welded lithic clasts and isolated mineral fragments thought to be regolith that assembled after major disruption fragmented large portions of the UPB mantle. In most polymict ureilites, the majority of clasts consist of material similar to monomict ureilites gardened from the UPB mantle but other materials, both endogenic and xenogenic to the UPB are also found in polymict ureilites, including clasts texturally and compositionally similar to known chondrite types as well as feldspathic melt rocks and clasts of Ca–Al–Ti-rich assemblages [1-4]. In this study, we demonstrate that polymict ureilites also contain a variety of metal and sulfide compositions of diverse origins. They offer insight into the final equilibrium conditions of disrupted portions of the UPB mantle and the diversity of materials locally available for regolith formation, and provide evidence for only limited post-regolith formation thermal metamorphism.

Methods: We analyzed major and trace elements in metal and sulfide phases in three polished thick sections each of EET 83309 and EET 87720 (pairing relationship uncertain) from the U.S. Antarctic Meteorite Collection first by EPMA at NASA Johnson Space Center and then by LA-ICP-MS at the National High Magnetic Field Laboratory/Florida State University using a New Wave UP213 (Nd:YAG 213 nm) laser ablation system coupled to a Finnigan Element ICP-MS. A working range of spot sizes of 40-100 µm were used. The IVB iron meteorite Hoba, the IIA iron meteorite Filomena, NIST SRM 1263a, and an in-house Peruvian pyrite standard (#1419) were used as external calibration standards. Corrected intensities were converted to elemental abundances by normalization wherein the sum of all analytes totals 100 wt% [5]. Analytical precision for most elements was <10% based on repeat measurements of calibration standards. In addition, we analyzed metals in DAG 999, DAG 1000, DAG 1023, and monomict ureilite NWA 1241 by EPMA.

Results and Discussion: Five distinct metal and sulfide phases were identified in samples EET 83309 and EET 87720. With the possible exception of metallic veins, this disequilibrium assemblage was inherited from breccia assembly. Temperatures of subsequent metamorphism were insufficient to have equilibrated metal and sulfide within these samples.

Troilite containing 0.1-0.9 wt% Ni and <0.1 wt% Co typically occurs in association with Fe,Ni or Fe,Si metals. In at least one instance, it appears to form a cross-cutting vein together with kamacite.

Pentlandite containing 6.6-10.9 wt% Ni and 0.2-0.3 wt% Co occurs within chondrite-like fragments resembling R-chondrites. These clasts contain no discernable Fe,Ni-metal phase. These clasts and the sulfides they contain are unrelated to any known portion of the UPB and never equilibrated with ureilitic material even after incorporation into the regolith.

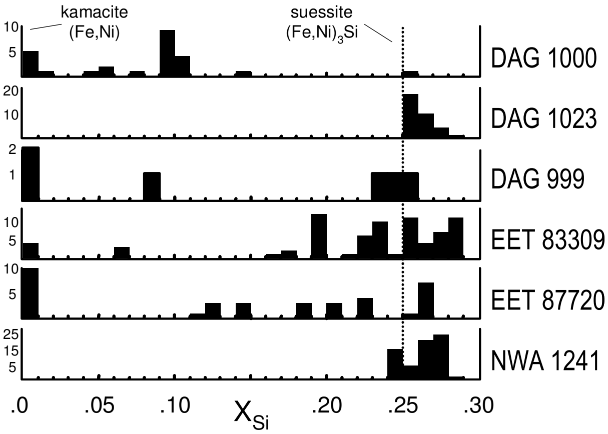

Figure 1. Histograms showing distribution of Si content of metals in several polymict samples and monomict ureilite NWA 1241 determined by EPMA. Vertical scale denotes number of point analyses.

Suessite was reported previously in the North Haig polymict ureilite [6] and monomict ureilite NWA 1241 [7]. Here we report its occurrence in five other polymict samples (Figure 1). To the best of our knowledge, these are the first trace element compositions of suessite yet reported. Moreover, they are a unique example of an Fe-metal phase simultaneously enriched in a light major element (Si) and in highly siderophile elements (compare with analyses of C [8] and P [9] bearing metals). Although more prevalent in EET

83309, Si-bearing metals occur in both EET samples as isolated fragments and as portions of clasts containing otherwise normal ureilite material. They contain 3.4-16.8 wt% Si with a distribution maxima at Fe_3Si, stoichiometrically pure suessite. Ni (0.5-4.6 wt%) and Co (0.1-0.4 wt%) contents are similar to kamacite grains. Chromium contents are typically higher (0-1.2 wt%) in suessite than in kamacite. Individual grains are relatively homogeneous at scales discernable by EPMA (~1µm). Trace siderophile elements in Si-bearing metals are highly fractionated. In particular, highly compatible siderophile elements (Pt,Ir,Os), are enriched relative to less compatible siderophile elements (Pd,Au) (Figures 2 & 3) in a manner similar to that observed in bulk ureilites, a characteristic thought to result from extensive partial melting of metallic phases [10-14]. This evidence in combination with the high T, low-fO_2 conditions required for suessite formation [7] indicate that suessite is likely derived from the UPB mantle and represent the latest stages of equilibrium, presumably immediately prior to some catastrophic disruption.

Fe,Ni-metal of kamacite composition (<0.25 wt% Si, 0.3-7.5 wt% Ni, 0.1-0.6 wt% Co, 0-0.2 wt% Cr) was observed in both EET samples in diverse petrographic occurrence but was more abundant in EET 87720. Trace siderophile element compositions of Si-free metals contrast sharply with those of Si-bearing metals in that the former have near-chondritic siderophile ratios or else are depleted in the most compatible siderophiles. Their compositions lend themselves to several potential explanations for their origins, and it is possible that there are distinct populations with different origins, including high-degree metallic partial melts from the UPB mantle and chondritic and achondritic xenogenic materials.

High-Ni metals, Fe-metal containing Ni in excess of what is considered kamacite (7.5-10.7 wt% Ni, 0.5-0.6 wt% Co, <0.2 wt% Si, <0.1 wt% Cr) are present as a minor component. These grains are surrounded by Fe-oxide rims and possibly they derived their high Ni and Co contents from oxidation of Fe. Trace element ratios of these high-Ni metals resemble those of kamacites in these samples but at higher abundances.

Conclusions: As observed for silicates, metals and sulfides in polymict ureilites exhibit diversity in composition and likely origin. Pentlandite is clearly associated with chondritic clasts unrelated to the UPB while troilite occurs in association with Fe,Ni and Fe,Si-metal phases. While suessite and kamacite share similar Ni and Co contents, their siderophile trace element compositions are distinct, suessites being consistent with formation in restitic mantle where known monomict ureilites formed, while Fe,Ni-metals formed as either a high degree melt from the UPB, as xenogenic additions, or as some combination of both.

References: [1] Guan Y. and Crozaz G. (2001) *Meteoritics & Planet. Sci.,* 6, 1039-1056. [2] Ikeda Y. *et al.* (2003) *Ant. Met. Res.,* 16, 105-127. [3] Cohen B. A. *et al.* (2004) *GCA*, 68, 4249-4266. [4] Goodrich C. A. *et al*. (2004) *Chem. der Erd*., 64, 283-327. [5] Campbell *et al.* (2002) *GCA* 66:647-660. [6] Keil K. and Berkley J. L. (1982) *Am. Min*., 67, 126-131. [7] Ikeda Y. (2006) *NIPR XXX*, 28. [8] Gangopadhyay A. *et al.* (2006*) LPS XXXVII*, #1456. [9] Campbell A. J. *et al.* (2003) *GCA*, 67, 3119-3134.[10] Goodrich C. A. *et al.* (1987) *GCA*, 51, 2255. [11] Goodrich C. A. *et al.* (1987) *Meteoritics*, 22, 392. [12] Janssens M. J. *et al.* (1987) *GCA*, 51, 2275. [13] Humayun M. *et al.* (2005) *LPS XXXVI*, #2208. [14] Warren P. H. *et al.* (2006*) GCA*, 70, 2104-2126.

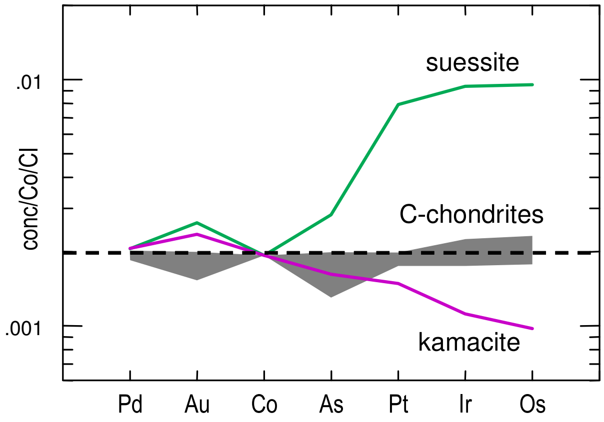

Figure 2. Average compositions of suessite and kamacite analyzed in samples EET 83309 and EET 87720 normalized to Co and CI-chondrite. Elements are in order of increasing compatibility under S-rich melting conditions. Composition field for carbonaceous chondrites is indicated.

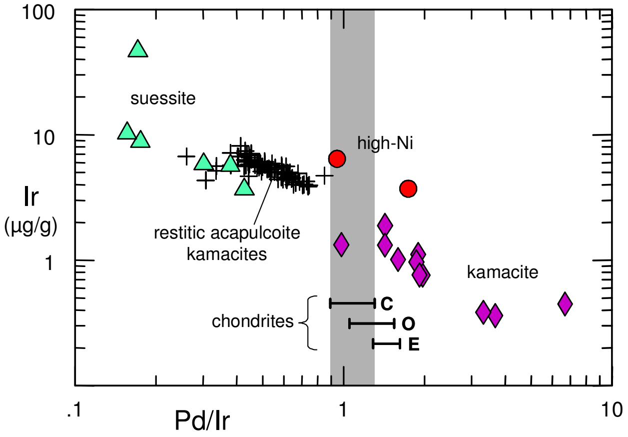

Figure 3. Variation in Pd/Ir among metal types (given different symbols) as a function of highly siderophile element (Ir) content. Pd and Ir are readily fractionated by metallic partial melting, Ir being significantly more compatible. Pd/Ir of different chondrite types is indicated. Like the suessites, restitic kamacites from acapulcoites have subchondritic Pd/Ir.