UREILITE VEIN METAL – INDIGENEOUS OR IMPACT MATERIAL? A. D. Gabriel[1] and A. Pack[1], [1]Geowissenschaftliches Zentrum, Goldschmidtstrasse 1, Universität Göttingen, 37077 Göttingen; a.gabriel@geo.uni-goettingen.de.

Introduction: Ureilites are ultramafic, igneous achondrites, which contain olivine (ol), pyroxene, metal and carbon. About ~10 vol% dark interstitial, fine-grained matter is usually referred as vein material [1]. Ureilites have lost ~25% basalt [2] and most of their metallic iron. Presently, many authors assume that the majority of ureilites formed as asteroidal melting residues [3, 4]. Although heterogeneous in oxygen isotopes [5], ureilites are suggested to originate from a single parent body that has been disrupted by impact. Variations in fayalite content are related to simultaneous smelting and melting at various depths [6].

The origin of the vein metal is not yet clear. While most authors assume it to be indigeneous [2, 6], we propose a metal rich impactor as metal source.

Metal composition: The concentrations Fe, Co, Ni, Si, Cr and P have been measured in the vein metal of the monomictic ureilites ALH 84136, ALHA 77257, EET 87517, EET 96042, LEW 85440 and GRA 95205. The ureilites represent the whole range of fayalite (fa) concentrations ranging from ~2 wt% FeO to ~20 wt% FeO in ol. Ni concentrations in vein metal range from 2.5 wt% to 6 wt%. The majority of the data lie between 3.5 and 5.5 wt% Ni. The concentrations of Co range from 0.25 wt% to 0.65 wt%, with most data lying between 0.35 wt% and 0.45 wt%. There is no correlation of Ni- or Co-concentrations with ol FeO. The Ni/Co-ratio of the vein metal is ~10 and lower than the chondritic Ni/Co-ratio of ~22 [7].

Thermodynamic calculations: Calculations of equilibration temperatures between ureilite ol and vein metal gave different temperatures for Fe-Ni and Fe-Co exchange reactions [8]. While equilibration temperatures for Fe-Co exchange generally give 900°C to 1250°C, Fe-Ni equilibration temperatures are unplausibly high ranging from 1300°C to 1900°C. Ureilite vein metal is not in equilibrium with ureilite ol at any temperature. The same calculations done for model metals for ureilite parent bodies (UPB) with CI1-, L-, H-, and CV3- chondritic composition give similar and plausible temperatures of about 1150°C for both exchange reactions [8].

Mass balance calculations: In order to understand if the vein metal could have been produced from the UPB or if an external source is needed, mass balance calculations were performed.

Most authors prefer a CI1- or CV3-like initial bulk UPB composition ([6],[9]). The amount and composition of metal available in the UPB depends strongly on the grade of oxidation of the UPB. The more oxidized the UPB, the more FeO is incorporated into the ureilite silicate and the smaller is the amount of Fe in the metal phase. For the UPB, the oxidation grade can be deducted from the amount of fayalite in ol. LA-ICP-MS measurements show only trace amounts of Ni and Co in ureilite silicate (19-105 µg/g Ni and 5-54 µg/g Co positively correlated with fa (also see: [8]). For mass balance calculations Ni, Co and S have been completely incorporated in the metal phase.

Mass balance calculations (mantle/core distribution) for a UPB with CV3-chondritic composition give Ni concentrations ranging from 5 wt% in a very reduced parent body (e.g. ALH 84136 $fa_{\sim 2}$) to 7.4 wt% in a very oxidized parent body (e.g. GRA 95205 fa_{20}). Co concentrations range from 0.25 wt% to 0.35 wt%. S would range from 8.5 wt % to 12.4 wt % in the UPB core. The calculated Ni-concentrations are higher than those observed in vein metal, while the calculated Co concentrations are lower than those observed in vein metal. Both, Ni and Co concentrations, show a correlation with ol FeO, whereas no correlation is observed between ureilite ol and ureilite vein metal.

If the vein metal has been formed within the UPB, it clearly has been subject to a fractionation process. Bulk rock analyzes indicate, that ureilites have lost most of their metal (~95%) possibly into a core [2].

Two mechanisms to model the fractionation process are equilibrium melting and batch melting of the ureilite metal. In order to correctly calculate the distribution of Ni and Co between liquid and solid metal, we use the Ni and Co distribution coefficients published in [10]. $D_{Ni}^{solid/liquid}$ ranges from 0.9 in S-free systems to 2.1 in Systems containing 30 wt% S. $D_{Co}^{solid/liquid}$ ranges from 1.0 in S-free systems to 4.5 in systems with 30 wt% S. For all calculations concentrations of Ni and Co decrease with increasing degree of melting. The results given here are calculated for removal of 95 wt% of metal as liquid. The vein metal is the treated as the residuum.

In a very oxidized UPB (~20 wt% FeO in mantle ol), equilibrium melting of metal would result in an increase of Ni and Co to 7.7 wt% Ni and 0.50 wt% Co in residual metal. Batch melting would first increase Ni as well as Co in the residual metal until all the S has been removed and then lower the amount of Ni in the residual metal, while leaving Co almost constant. With 95% of the metal removed, the residual metal would still contain 7.5 wt% Ni and 0.51 wt% Co.

For a very reduced UPB ($fa_{\sim 2}$ in mantle ol), equilibrium melting gives a residual metal with 5.0 wt% Ni and 0.31 wt% Co. Batch melting gives 4.5 wt% of Ni and 0.31 wt% Co.

For a very oxidized UPB both mechanisms fail to explain the low Ni concentrations and Ni/Co ratios obseved in vein metal. For a very reduced parent body composition batch melting results in Ni and Co concentrations that are similar to ureilite vein metal. However, the majority of ureilites do show ol with fa_{20} [1]. We therefore assume, that Ni and Co concentrations in ureilite vein metal are not a result of solid/liquid fractionation of metal on a UPB with CV3-chondritic composition.

A UPB with a initial CI1-like composition would generally contain more S, which would result in even higher Ni and Co concentrations in the residual metal.

We suggest that the vein metal is not indigenious to the UPB but hast been injected through an impact into the ureilite mantle.

Iron meteorites show a wide range of Ni-concentrations and Ni/Co-ratios (Fig. 1). The members of the IIAB-group show low Ni-concentrations of 5.5-6.0 wt% and Ni/Co-ratios of ~12. The rare iron meteorites of the Bellsbank-group, show even lower Ni concentrations of about 4.5 wt% and Ni/Co-ratios of ~10 [11],[12],[13]. The existence of a iron meteorite, that could have delivered the vein metal with ~4.0 wt% Ni and a Ni/Co-ratio of ~10 appears therefore plausible. In order to produce a metal composition similar to ureilite vein metal, the impactor needs to be extremely reduced, with FeO almost completely in the metal core. This will result in low Ni and Co concentrations in the metal. S concentrations need to be moderate (~15 wt%) as high S will increase Ni in the solid metal, but low S would produce high Ni/Co ratios.

This would also explain the disequilibrium between ureilite ol and the vein metal. Recent studies of Ni-isotopes in ureilite vein metal and silicate [14] have also revealed a heterogeneity – the vein metal having $\varepsilon^{60Ni} = 0.0$ (similar to iron meteorites), the silicate having $\varepsilon^{60Ni} = -0.12$ to -0.77.

Conclusion: Ni and Co concentrations in ureilite vein metal can not be explained with solid/liquid-fractionation of metal in a UPB with CV3- or CI1-chondritic composition. Ureilite vein metal is not in equilibrium with ureilite ol at any temperature and Ni-isotopes show heterogeneities between vein metal and ureilite silicate. We therefore conclude that a Ni-poor iron-meteorite impactor is the source of the vein metal, while the indigenious UPB metal was efficiently removed during core formation. Ureilite vein metal is similar in composition to IIAB- or Bellsbank-group iron meteorites. It is therefore concluded, that the impactor was a highly reduced object with little FeO in the silicate portion and low Ni in the core. The vein metal represents material from the already solidified core of this object.

References:

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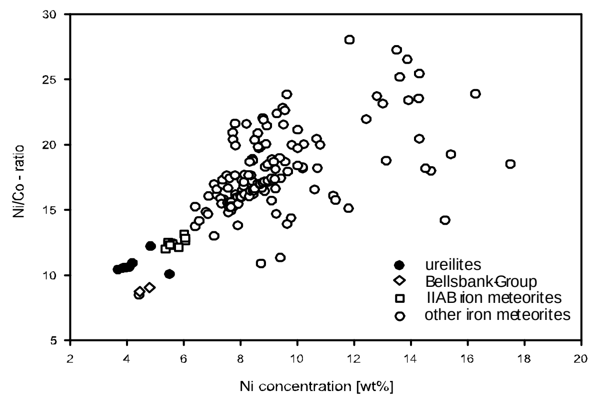

Fig. 1 Ni/Co-ratio vs. Ni concentrations in iron meteorites and ureilite vein metal.