SIDEROPHILE ELEMENT ABUNDANCES IN KARAVANNOE: IMPLICATIONS FOR THE ORIGIN OF THE EAGLE STATION PALLASITES.
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Introduction: The link between chondritic meteorites and differentiated meteorites is an important goal that is often elusive, with the exception of isotopic finger-printing [e.g., 1-2]. To understand the paleomagnetism of CV chondrites models of a partially differentiated asteroid, with a carbonaceous chondritic surface and a differentiated interior, have been proposed [3-4]. Chemical tests of this model supported the idea that CV chondrites may be linked to the Eagle Station pallasite trio (ESP) on the basis of siderophile element measurements of metal from Eagle Station and Cold Bay [5]. The range of chemical fractionation in the ESP meteorites is rather limited, so the recent discovery of a new member, Karavannoe [6], provides the opportunity for an improved test using siderophile elements. Olivine from the Karavannoe pallasite has oxygen isotope compositions and mineral chemistry (Fe/Mn~97, Fa~20) that identify it as the fourth member of the Eagle Station Pallasites (ESP). Further, the metal in Karavannoe is plessite with swathing kamacite around the olivines [6]. This is important since the main challenge to chemical fingerprinting of pallasites by laser ablation ICP-MS [5] is coarse subsolidus exsolution of kamacite and taenite [7]. For example, the siderophile element data for Cold Bay are affected by the preferential dissolution of kamacite during weathering so that measured siderophile element patterns have a strong taenite overprint [8].

Analytical Methods and Samples: A 19 mm x 12 mm sawn slab of Karavannoe with minimal weathering was received from the Russian Academy of Sciences Committee on Meteorites, mounted in epoxy, and polished on one side exposing >50% metal with weathering restricted to the olivine-metal contacts. Siderophile elements were determined by rastering three olivine-free metallic areas each ~3-4 mm^2. Laser ablation ICP-MS analysis were performed with a New Wave UP193FX excimer laser system coupled to a Thermo Element XR at the Plasma Analytical Facility, Florida State University. A 100 µm beam spot scanned at 10-25 µm/s, 50 Hz repetition rate, 2 GW/cm^2 fluence, was used. Other aspects of the measurement are identical to those previously described [5].

Results: The siderophile element data for Karavannoe are given in Table 1, together with results for Eagle Station, shown in Fig. 1. The success of measuring small areas by laser ablation and estimating the bulk metal composition in a pallasite is judged in terms of obtaining meaningful representation of kamacite and plessite (in the case of Karavannoe) or taenite. Fig. 2 shows the correlation between the $(Co/Ni)_{CI}$ and the $(As/Au)_{CI}$ ratios. Kamacite concentrates Co and As, while taenite concentrates Ni and Au. Individual analyses of Cold Bay cover a broad range of composition, while analyses of Eagle Station and Karavannoe are nearly constant at chondritic ratios of Co/Ni.

Table 1: Siderophile element abundances (ppm) in Karavannoe (this study), Eagle Station and CV metal.

	Eagle Station	Karavannoe	CV Metal
W	0.40	0.27	0.13
Re	1.64	0.85	0.82
Os	21.5	10.4	10.0
Ir	16.2	9.55	9.42
Ru	23.8	16.4	14.1
Pt	28.9	19.2	18.2
Rh	3.00	2.30	2.32
Mo	17.3	15.7	14.0
Ni	182000	169000	178000
Co	8850	8190	8720
Pd	5.81	6.06	8.90
Fe	808000	812000	811000
Au	1.17	1.36	1.92
As	8.70	10.4	21.3
Sb	0.48	0.29	1.13
Cu	560	301	1330
Ga	5.6	3.0	9.29
Ge	78	81	173
Sn	0.88	0.29	12.0

Korochantsev et al. [6] reported bulk metal siderophile element composition for Re, Ir, Pt, Rh, Mo, Ni, Co, Pd, Fe, As and Ga. The Ni content (14.0 wt %) and the Ni/Co ratio (18.5) obtained by XRF are lower than that obtained here (16.9 wt %; 20.6). The Ni/Co ratio obtained in this study is identical to that of Eagle Station (20.6) and to that of CV metal (20.4, [5]). The earlier ICP results indicated a composition more depleted in compatible siderophile elements, with CI- and Ni-normalized abundances for all the compatible siderophile elements below unity [6]. Our data on a different piece of Karavannoe are closer to the Eagle Station composition, with compatible sideophile elements enriched relative to CI (Fig. 1). Because the bulk ICP data of [6] are systematically lower in compatible elements and similar in incompatible elements, to the new LA-ICP-MS data the difference between our data and that of [6] has to be ascribed to chemical zonation within the large Karavannoe mass (132 kg, [K]), which may provide an opportunity to better define the internal fractionation in Karavannoe.

Discussion: Korochantsev et al. [6] noted several features of the siderophile element pattern of Karavannoe that resembled that of Eagle Station pallasites, including the high Ni contents and the depletion in Ga, all of which are confirmed here. Further, we add that the striking depletions of W, Fe and Ga relative to a CV chondrite composition are equal in Eagle Station and Karavannoe (Fig. 1). These features are related to formation under oxidizing conditions required to stabilize high Ni alloy. Karavannoe falls almost directly on the CV chondrite metal composition line [5], except that it has lower Pd and other incompatible elements (Au, As, etc.). In terms of establishing a genetic relationship to the CV chondrites, Karavannoe nicely follows the calculated pattern of a solid metal formed from a CV metallic liquid [5] after some degree of fractional crystallization to remove earlier solids represented by Eagle Station. The exact degree of fractionation required to match the Karavannoe pattern is determined by the S content of the liquid, which is not easy to constrain a priori. In our earlier work [5], we assumed no sulfur in the liquid. However, to match the Cu abundances we require about 3-6 wt % S in the initial liquid, otherwise, the calculated solid metal Cu abundances formed from CV metallic liquid [5] are too high for ESP metal.

The fit to the incompatible elements is best for Au, As, and Sb, but our early attempts at fitting other incompatible siderophiles were not satisfactory. A significant issue is the fit of Cu and Ge. The partition coefficient of Cu has always been difficult to parameterize in terms of the Fe domains model [9]. The latest parameterization [10] produces a linear decrease of D(Cu) with increasing S content in the liquid, which poorly matches the experimental data at S<10 wt%. Accordingly, using the experimental D(Cu) as a function of S content from 0-10 wt%, we obtained a linear fit that passes through all the experimental data. This parametrization of D(Cu) yielded much lower Cu contents in the modeled metallic solids at low S contents in the liquid so that Cu abundances in Karavannoe and Eagle Station fit the CV-liquid model now (Fig. 1).

Thus far, a fit to Ge remains difficult to achieve since Ge does not vary significantly in its solid metal-liquid metal partition coefficient. However, the temperature dependence of the metal-silicate partition coefficient is not well known [11]. The fit to the most volatile elements between a calculated CV metal composition and the Eagle Station Pallasites is sufficiently close that further refinement of the model is desirable.

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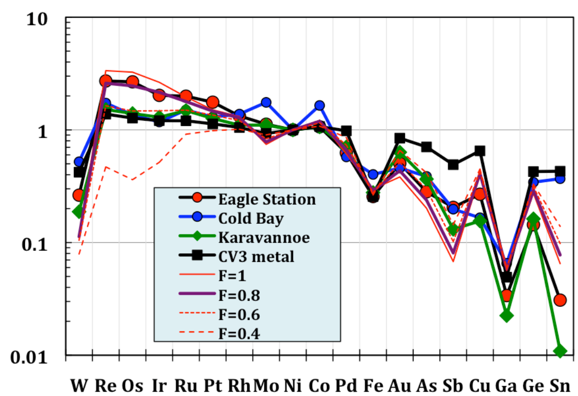

Figure 1: Siderophile element patterns on a Ni- and CI-normalized plot for Karavannoe (this study) compared with Eagle Station and Cold Bay, and with a metal derived from CV chondrites [5]. Model calculations for solid metal precipitated from the CV chondrite metal [5] by fractional crystallization are shown as lines marked with the fraction of liquid remaining (F).

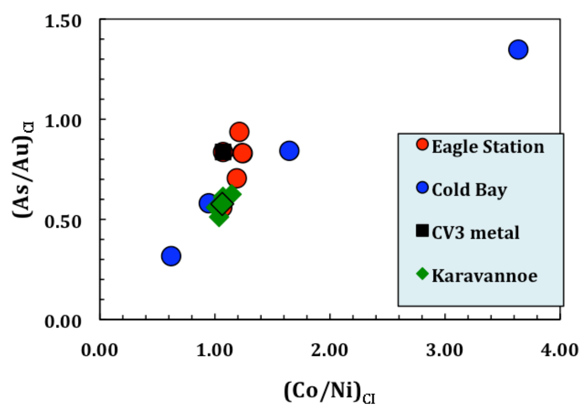

Figure 2: The signature for kamacite-taenite fractionation.