**KARAVANNOE: A NEW MEMBER OF THE EAGLE STATION PALLASITE GROUPLET.** A. V. Korochantsev[1], C. A. Lorenz[1], M. A. Ivanova[1], S. N. Teplyakova[1], N. N., Kononkova[1], I. A. Roshina[1], S.E. Borisovsky[2], Ya. V. Bychkova[2], I. A. Franchi[3], R. C. Greenwood[3]. [1]Vernadsky Institute of Geochemistry and analytical chemistry, Kosygin St., 19, Moscow, Russia, 119991, korochantsev@geokhi.ru; [2]Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry; [3]Open University, Milton Keynes, MK7 6AA, UK., i.a.franchi@open. ac.uk

**Introduction:** A new meteorite, Karavannoe, was recently found in Russia. It is the fourth and the heaviest member (132 kg) of the small Eagle Station pallasite grouplet (ES) including Eagle Station (36 kg), Cold bay (0.32 kg) and Itzawisis (0.35 g). Here we describe circumstences of the Karavannoe pallasite find and report results on its petrography, mineralogy, chemistry and oxygen isotope composition.

**History of discovery:** One stone weighing 132 kg was found by brothers, Sergei and Alexander Blednykh in a street of the Karavannoe village, Tuzhinsky region, Kirovsky district. The existence of the stone was known about since the early 1960s, but only in 2010 was its significance recognized and the specimen was then sent to Vernadsky Institute for detailed investigation. The meteorite has an irregular shape, 32 x 42 cm in size, and shows no sign of fusion crust. The surface of the pallasite is very weathered and rusty (Fig. 1).

**Analytical procedures:** The meteorite was studied by optical microscopy in reflected light. Mineral chemistry was investigated by EPMA, major and trace element compositions of Fe,Ni-metal were determined by XRF and ICP analyses. Oxygen isotope analysis was performed by infrared laser-assisted fluorination [A] on a ~ 2mg sample of separated olivine chips from Karavannoe. Analytical precision (1σ) is approximately: ±0.040‰ for $\delta^{17}O$; ±0.080‰ for $\delta^{18}O$; ±0.024‰ for $\Delta^{17}O$ [1].

**Results.**

The meteorite has a typical pallasite texture. It consists of coarse-grained greenish-yellow olivine enclosed in Fe,Ni-metal.

*Silicate and oxide mineralogy and composition:* Olivine grains are very fractured, the cracks and fractures are othen filled by weathering products. Modal olivine content is in the range: 20-25 vol%. Olivine contains small grains of chromite, pyroxene and Fe,Ni-metal. Olivine composition is $Fa_{19.7}$ (Fe/Mn=96.8 at; CaO 0.01 wt%, $Cr_2O_3$ 0.09 wt%). Accessory low-Ca pyroxene occurs within the olivine crystals as small inclusion and has the following: composition: $Fs_{16.8}Wo_{1.4}$ (Fe/Mn=54 at; 0.36 wt% $Al_2O_3$; 0.32 wt% $Cr_2O_3$). Tiny inclusions of Ca-phosphate, probably whitlockite, were found on the contacts of olivine and Fe,Ni-metal. Chromite occurs as rare inclusions in olivine and consists of aligned needles, 0.2-0.5 µm in width, and 20-100 µm in length, and also occurs as clusters of subhedral isometric grains, 5-10 µm in size.

*Opaque phases mineralogy and composition:* The Fe,Ni-metal consists of irregular martensite fields 0.1x0.5 to 0.5x1.5 mm in size, the margins of which are decorated by wavy kamacite bands, 0.05-0.5 mm in size. Martensite fields comprise micro-widmanstatten intergrowths of tiny taenite and kamacite grains. Occasionally, martensite contains straight linear kamacite lamellae, 10-35 µm in width, surrounded by high-Ni taenite bands, 2-4 µm in width. Rarely, the lamellae occur as linear chains of kamacite lenses. Each kamacite lense contains a shreiberzite crystal in the core.

Troilite, usually associated with minor high-Ni sulfide or Fe,Ni-metal, forms spherical inclusions in olivine, 5-20 µm in diameter. In several places, these troilite globules are grouped into linear chains. Sometimes we observed a partial melting of the troilite globules, that lead to formation of sulfide veinlets filling the cracks in olivine. The metal-troilite melt pockets of eutectic-like composition are also associated with troilite veinlets in the fractured olivine. Rare fine-grained intergrowth of silicate, Fe,Ni-metal grains, and Ca-phosphate could represent an additional type of melt pockets.

*Bulk chemistry of Fe,Ni-metal:* Bulk Ni content in FeNi-metal, determined by XRF, is 14 wt% (Ni/Co = 18.5). The siderophile element data, obtained by ICP, are shown on a Ni-, CI-normalized plot in Fig. 2, together with the bulk ES pallasite metal.

*Oxygen isotopic composition:* The oxygen isotope composition of the Karavannoe olivine is: $\delta^{17}O$ = -6.25 ‰; $\delta^{18}O$ = -2.64‰, $\Delta^{17}O$ = -4.88 ‰ (Fig. 3).

**Discussion:**

The Karavannoe olivines are similar to those of other ES olivines in MG# and Fe/Mn ratio, but they contain less CaO and $Cr_2O_3$ [2]. The Fe,Ni-metal of Karavannoe is poor in Ni in comparison with average Ni content of the Eagle Station pallasite and has intermediate Ir content between the ES and Milton pallasites [3]. It was shown [4] that chemical composition of the ES pallasites is plausibly derived from differentiation of CV chondrites material. Based on this model calculation [4] we could tentatively propose that the Karavannoe composition is consistent with crystallization of solid metal from a parental CV3 metallic liquid after more than 60% fractional crystallization (see Fig. 2 of [4]).

The cm-sized crystals of olivine with igneous chromite needles are likely to have originated from the interior of a differentiated body. The rounded shape of medium- and small-sized olivine grains in the Karavannoe pallasite strongly suggests that some portion of olivine was completely melted during the mixing of olivine and metal. The large troilite globules in the olivine could also be formed during this large scale melting. This most likely took place during a catastrophic disruption of the Karavannoe parent body. The melt pockets, troilite veinlets and chains of inclusions in the olivine indicate at least one more impact event in the Karavannoe history. The structure of Fe,Ni-metal could correspond to an annealing episode due to this impact heating event.

The Karavannoe oxygen isotope composition exactly corresponds to that of the ES pallasite grouplet, and is located close to the Allende mixing line (AM) on a three isotopes oxygen plot (Fig. 3). There appears to be a possible trend (mixing line), parallel to the AM connecting the ES cluster, Bocaiuva silicate-bearing iron, several anomalous irons [5] and the Milton ungrouped pallasite [6]. This may indicate an origin of these meteorite groups from a common oxygen reservoir.

Based on our investigation and previous works we can conclude that the Karavannoe pallasite could have formed in the interior part of a parent body as a result of its extensive melting and differentiation. The Karavannoe pallasite mineralogy, bulk chemistry of Fe,Ni-metal and oxygen isotopic compositions indicate that it was probably originated from CV3-like material. The primary heat source for the Karavannoe parent asteroid would likely be the energy of $^{26}Al$ decay and impact events during cooling process to produce the observed textures of the pallasite. The fact that the Earth is continuously accumulating the ES meteorites suggests that the ES parent body has a significant size, or at least the secondary body (-s) could exist in Solar system and probably could be discovered among metal-silicate asteroids of the Main Asteroid Belt.

**References:** [1] Miller M. F. et al. (1999). *Rapid Commun. Mass Spectrom.* 13, 1211-1217. [2] Mittlefehldt D. W. et al. (1998), *Rew. In Mineral., 36*, 4-40. [3] Hillebrand J. T. et al. (2004) *LPSC XXXV*, Abstract 1278. [4] Humayun M., Weiss B. P. (2011) *LPSC XLII*, Abstract 1507. [5] Clayton R. N., Mayeda T. K. (1996) *Geochim. Cosmochim. Acta, 60*, 1999-2018. [6] Larson T., Sharp Z. (2003) *Meteoritical Bulletin, 87, Meteoritics & Planet. Sci., 38*, A189-A248.


Fig. 1. The Karavannoe pallasite.

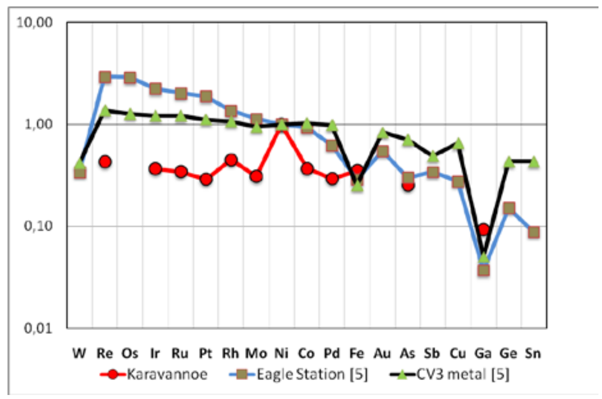


Fig. 2. Ni-, CI chondrite-normalized siderophile element abundances in Eagle Station [4] and Karavannoe, in comparison with the CV3 metal [4].

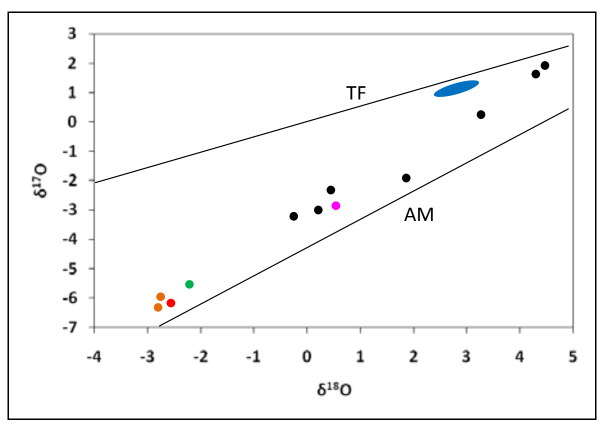


Fig. 3. Oxygen isotopes composition of the Karavannoe olivine (red) in comparison with that of ES (orange), Bocaiuva (green), ungrouped irons (black), MG pallasites (blue) [5], and Milton pallasite (pink) [6].