

**MILTON: A NEW, UNIQUE PALLASITE.** R. H. Jones<sup>1,3</sup>, J. T. Wasson<sup>2</sup>, T. Larson<sup>3</sup> and Z. D. Sharp<sup>3</sup>, <sup>1</sup>Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, U.S.A. (e-mail: rjones@unm.edu); <sup>2</sup>Institute of Geophysics, UCLA, Los Angeles, CA90095-1567, U.S.A.; <sup>3</sup>Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, U.S.A.

**Introduction:** The Milton pallasite was found in Missouri, U.S.A. in October, 2000. It consists of a single stone that originally weighed approximately 2040 g. The chemistry of the olivine and metal phases, plus the oxygen isotope ratios of the olivines, differ significantly from other pallasites, making Milton unique. Unfortunately, the meteorite is heavily fractured and weathered.



Fig. 1. Polished slice of Milton. Coin is 20mm across.

**Petrography:** The interior of the stone consists of relatively small (mean grain size 1.6 mm), angular olivine grains (~73 vol%) in an iron metal matrix (Fig. 1). Ferric oxides are abundant. Samples easily fragment because of the weathering and numerous, probably preterrestrial, fractures. Olivine contains numerous small (typically 50  $\mu\text{m}$  diameter) inclusions, visible in the SEM, that consist of kamacite, taenite, sulfides, phosphates, and chromites.

**Olivine chemistry:** Olivine compositions were determined by electron microprobe analysis at UNM.

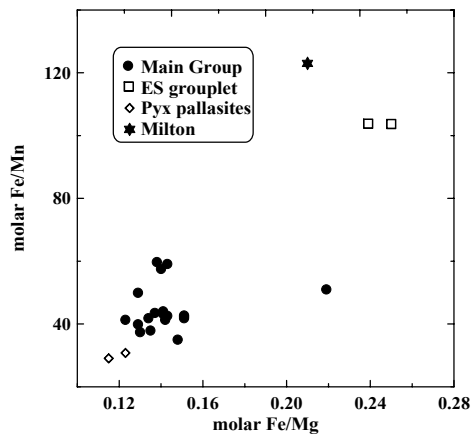


Fig. 2: Olivine chemistry in pallasites, after [1]. Pyroxene pallasite data from [2].

The mean olivine composition in Milton is:  $\text{SiO}_2 = 39.0$ ,  $\text{Cr}_2\text{O}_3 = 0.09$ ,  $\text{FeO} = 16.4$ ,  $\text{MnO} = 0.13$ ,  $\text{MgO} = 44.3$ ,  $\text{CaO} = 0.12$  (all wt%); mean Fa = 17.2 mole%.

Milton olivine is FeO-rich compared with most main-group (MG) pallasites, and has a high molar Fe/Mn ratio (123; Fig. 2). Milton olivine appears to have chemical affinities to the Eagle Station (ES) pallasite grouplet, although its composition is not identical. Olivine shows minor element zoning: FeO and MnO contents are fairly uniform from the cores to the edges of grains, while  $\text{Cr}_2\text{O}_3$  and CaO show marked zoning, decreasing towards grain edges, for example CaO decreases from 0.20 to 0.07 wt% and  $\text{Cr}_2\text{O}_3$  decreases from 0.14 to 0.06 wt%.

**Iron metal chemistry:** The iron metal composition was determined by INAA at UCLA. The preliminary composition is as follows: Ni, 150 mg/g; Co, 9.6 mg/g; Cr, 1550; Cu, 168; Ga, 15; As, 10; W, 2.0; Re, 6190; Ir, 50; Pt, 32; Au, 1.16 (all  $\mu\text{g/g}$ ). The metal composition is compared with other pallasites on an Ir-Ni plot in Fig. 3. Milton is very different from the main-group pallasites and, despite the similarity in Fig. 3, it is also significantly different from the ES pallasites.

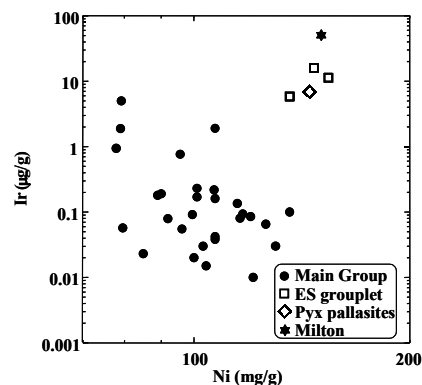


Fig. 3. Metal chemistry in pallasites, after [1].

**Oxygen isotope ratios of olivine:** Olivine grains extracted from Milton were analyzed for oxygen isotope ratios by a laser fluorination technique using the Finnigan Mat Delta Plus XL mass spectrometer at UNM [3]. Errors on individual measurements are  $\pm 0.2$  ‰ for  $\delta^{17}\text{O}$  and  $\pm 0.1$  ‰ for  $\delta^{18}\text{O}$ . Three fragments of Milton olivines (each ~ 2 mg) were analyzed, and the results were all very similar (Table 1; Fig. 4).

For comparison, we also analyzed olivine from the Eagle Station and Marjhalati pallasites (Fig. 4). Our

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ES analysis plots very close to that of Clayton [4]. In contrast, our Marjhalati data are higher in both  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O}$  than Clayton's data, by about 1 ‰. We also analyzed San Carlos olivine and obtained a  $\delta^{18}\text{O}$  value of 5.35 ‰, which compares well with the value of 5.25 ‰ obtained independently [5]. We are currently investigating the discrepancy in the MG pallasite data.

**Table 1: Oxygen isotope ratios of olivine from pallasites, relative to SMOW.**

		$\delta^{18}\text{O}$	$\delta^{17}\text{O}$	$\Delta^{17}\text{O}$
<b>Milton</b>	1.	0.64	-2.95	-3.28
	2.	0.57	-2.67	-2.97
	3.	0.34	-2.98	-3.16
	<i>mean</i>	<i>0.52</i>	<i>-2.87</i>	<i>-3.14</i>
<b>Eagle Station</b>		-2.68	-6.22	-4.82
<b>Marjhalati</b>	1.	4.14	2.40	0.25
	2.	4.15	2.10	-0.06
	3.	3.50	1.86	0.04

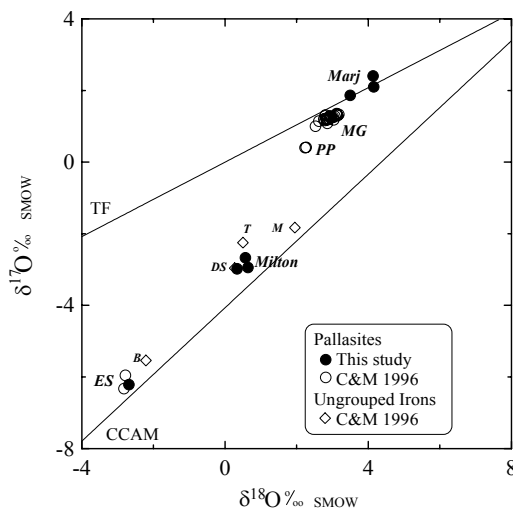


Fig. 4. Oxygen isotope ratios of Milton olivine compared with other pallasites and selected ungrouped irons. Pallasites include main group pallasites (MG), Marjhalati (Marj), pyroxene pallasites (PP), and the Eagle Station (ES) grouplet. Ungrouped irons are Tucson (T), Mbosi (M), Deep Springs (DS), and Bocaiuva (B). Data from this study and [4].

Milton is clearly resolved from both the ES and main group pallasites in Fig. 4. Although Milton lies between the ES and MG pallasites on the oxygen diagram, but it does not lie on a straight line between the two, hence it appears that the groups are not related by mixing. Like the ES grouplet, Milton lies close to the CCAM line and shows oxygen isotopic affinities to carbonaceous chondrites [4, 6].

**Discussion:** Milton appears to be a unique pallasite, in terms of its olivine chemistry, iron metal chem-

istry and the oxygen isotope ratios of its olivine. This probably means that it is material from an asteroid previously unrepresented in the pallasite record. ES pallasites show chemical and oxygen isotopic affinities to the ungrouped iron, Bocaiuva. Likewise, we can investigate whether Milton may be associated with any iron meteorites. Figure 4 shows the oxygen isotope ratios of silicates in three ungrouped irons that all lie close to the oxygen isotope ratio of Milton olivines: Tucson, Mbosi and Deep Springs [4]. However, we can exclude direct associations between Milton and any of these meteorites based on iron chemistry: Co contents of the three iron meteorites are significantly lower than in Milton: 4.3, 7.8 and 6.3 mg/g respectively (unpublished data, JTW), compared with 9.6 mg/g in Milton. In terms of iron chemistry, Milton appears to be most closely associated with the ungrouped iron meteorites, South Byron and Babbs Mill (Troost's), although these are not exact matches.

Minor element zoning in pallasite olivine has been described previously [7, 8]. Decreases in CaO and  $\text{Cr}_2\text{O}_3$  towards the edges of olivine grains are observed in several pallasites. MnO may either increase towards grain edges or show no zoning, as in Milton. [7] interpreted the zoning profiles as being diffusion-generated, with diffusion coefficients decreasing in the order  $\text{Mn} > \text{Ca} > \text{Cr} > \text{Al}$ , and [8] used zoning profiles to determine pallasite cooling rates, based on diffusion calculations. However, under reducing conditions, where Cr is likely to be present as  $\text{Cr}^{2+}$ , Cr diffusion in olivine is significantly faster than Ca diffusion [9]. An alternative explanation for the zoning is that it is related to chromite and phosphate nucleation and growth, possibly in response to mild oxidation. If this is the case, zoning in olivine cannot be used to derive pallasite cooling rates.

**References:** [1] Mittlefehldt, D. W. et al. (1998) Planetary Materials, Rev. Min. vol. 36, Chapter 4. [2] Boesenberg J. S. et al. (2000) MAPS 35, 757-769. [3] Sharp Z. D. (1995) Am. J. Sci. 295, 1058-1076. [4] Clayton, R. N. and Mayeda T. K. (1986) GCA 60, 1999-2018. [5] Eiler, J. M. et al. (1995) Nature 377, 138-141. [6] Shukolyukov, A. and Lugmair, G. W. (2001) LPSC XXXII, #1365. [7] Zhou, Y. and Steele, I. M. (1993) LPS XXIV, 1573-1574. [8] Miyamoto, M. and Takeda, H. (1994) LPSC XXV, 921-922. [9] Jones R. H. and Lofgren G. E. (1993) Meteoritics 28, 213-221.

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