NEW PYROXENE PALLASITES: BORDJI BADJI MOKHTAR 001 AND GYARUB ZANGBO, AND A PLETHORA OF PALLASITE PARENT BODIES. J. S. Boesenberg[1], M. Humayun[2], A. J. Irving[3], and D. E. Ibarra[1], [1]Dept of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook Street, Providence, RI 02920 (joseph_boesenberg@brown.edu). [2]National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL 32310. [3]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA, USA

Introduction: Bordji Badji Mokhtar 001 and Gyarub Zangbo are two recently classified pallasites from Algeria and China (Tibet), respectively. Bordji Badji Mokhtar 001 (BBM 001) was listed as a new pyroxene pallasite containing about 1% orthopyroxene, while Gyarub Zangbo (GZ) was simply classified as a pallasite containing Fa_{21} olivine. Given that this olivine composition is typical of the Eagle Station Group, the sample was pursued primarily to obtain trace element analysis of the metal for comparison. However, upon petrologic examination with the electron microprobe, it was determined to contain orthopyroxene and is now the tenth known pyroxene pallasite. Here we investigate the petrological, chemical and oxygen isotopic history of the samples and the implications for common differentiation and crystallization processes among protoplanets in the early solar system.

Analysis: Petrologic examination and electron microprobe analysis of both samples was accomplished at Brown University, whereas elemental analysis of the metal was performed at Florida State University. There are plans to obtain confirmation oxygen isotopic analysis for BBM 001 and new analysis for GZ at the new Brown University (D. Ibarra) oxygen isotope laser fluorination laboratory.

Results: *Bordji Badji Mokhtar 001* is a typical pyroxene pallasite petrologically, containing large 5-10mm, rounded to sub-rounded olivine ($Fa_{12.5-14.3}$, Fe/Mn = 34-43) (5-10mm diameter) in a metal matrix composed of kamacite and plessite. The swathing kamacite typically surrounds the olivines, with the interior portions of the metal containing the plessite. Orthopyroxene typically occurs with troilite, merrillite, olivine +/- chromite along the edges and interiors of the larger olivines in coarse symplectite assemblages, very common in pyroxene pallasites. The orthopyroxene ($Wo_{0.2}En_{87.2}$ to $Wo_{0.7}En_{85.4}$, Fe/Mn = 20-26, 0.11-0.33 wt% Cr_2O_3), along with the merrillite and troilite are not simple rounded grains, but typically are 50-200 microns in diameter, having very non-symmetrical, commonly triangular morphologies. The orthopyroxene in BBM 001 is always associated with merrillite, but a few larger merrillites found adjacent to large olivines do not appear to be associated with orthopyroxene. Their respective compositions however do not differ. BBM 001 contains abundant, very Al-rich chromite [Al/Al+Cr) x 100 = 34.5-36.5, (Fe/Fe+Mg) x 100 = 56.9-61.9, 17.4-19.6 wt% Al_2O_3] that occurs as rounded to sub-rounded grains, up to 500 micron in diameter, and often forming clusters (Fig. 1). Merrillite as mentioned above, varies in morphology, but it is quite uniform in composition (3.4-3.9 wt% MgO, 0.13-0.33 wt% MnO, 0.15-0.5 wt% FeO, and 0.27-0.39 wt% Na_2O). Schreibersite is common in the metal, but troilite is only rarely found outside the coarse symplectite assemblages.

Table 1. All data in ppm.

	BBM001	GZ
Fe	862000	804000
Co	5010	6960
Ni	112000	188000
Cu	170	654
Ga	24.2	14.9
Ge	61.9	24.0
As	21.6	20.6
Mo	10.9	9.6
Ru	4.36	11.4
Rh	1.13	1.42
Pd	6.08	11.1
Sn	1.02	0.50
W	0.64	1.40
Re	0.15	1.25
Os	1.38	16.4
Ir	1.63	14.7
Pt	5.85	15.4
Au	2.82	2.61

Elemental analysis of BBM 001 metal (Table 1) shows that it typically plots among the shotgun distribution of the Main Group pallasites and IIIAB irons (Fig. 2). For BBM 001, the metal is Ir-rich indicating it crystallized early in contrast to many Main Group pallasites that have low Ir-metal (Fig. 3).

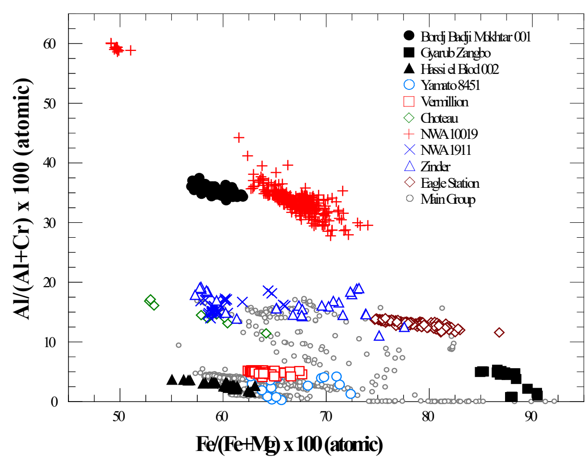

Figure 1. Chromite Fe/(Fe+Mg) vs Al/(Al+Cr) plot for all pallasites. Chromites in BBM 001 and NWA 10019 are Al-rich, whereas those in GZ are the most Fe-rich.

Oxygen isotopes measured by K. Ziegler at UNM plot below the field for Main Group pallasites and just above the mesosiderite field ($\Delta^{17}O \sim -0.23$, ref slope = 0.526) [2].

Gyarub Zangbo is an unusual pyroxene pallasite containing the most Fe-rich olivine and chromite found in any pallasites. The olivines ($Fa_{20.9-22.4}$ Fe/Mn 53-68) within GZ are relatively small (up to 5mm diameter) and contain the full range of crystal shapes from rounded to angular. The orthopyroxene ($Wo_{0.2}En_{79.5}$ to $Wo_{0.5}En_{80.9}$, Fe/Mn 35-40, 0.12-0.17 wt% Cr_2O_3), occurs both as part of orthopyroxene-troilite-olivine coarse symplectite assemblages, much like in BBM 001, and as single rounded grains attached to the exterior edges of larger olivines. Most orthopyroxene grains range in size from 50 to 200 microns. GZ contains scarce, small (20-40 micron diameter), low-Al chromite [(Al/Al+Cr) x 100 = 0.7-5.3, (Fe/Fe+Mg) x 100 = 85.3-90.5, 0.33-2.43 wt% Al_2O_3]. Swathing kamacite and interior taenite are both present. Elemental analysis of the metal shows that on the Ga-Au diagram (Fig. 2), GZ metal plots where metal in Main Group pallasites merge with the IIIAB irons. On the Ir-Au plot (Fig. 3), GZ plots beyond the extreme Ir-rich end of Main Group pallasites, indicating it contains early crystallizing metal. The Ga content (15 ppm) is higher, and the Ge content (24 ppm) is lower than Eagle Station pallasites (3-9 ppm Ga; 75-130 Ge). The high-Ni content is higher than that found in IVB irons or Eagle Station pallasites and together with Ga-Ge contents, places this pallasite in ungrouped status. Other phases found within GZ include troilite and schreibersite. No phosphates however were found. Oxygen isotopes for GZ are pending.

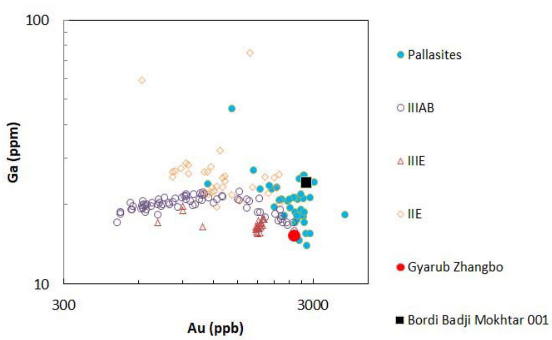

Figure 2. Au vs Ga elemental metal analysis for BBM 001 and GZ. Both plot in the field of Main Group pallasites.

Discussion: BBM and GZ likely have similar core crystallization histories despite their different compositions. Both have high Ir metal, which implies that the core crystallization would be downward (inward), assuming these are mantle samples and they formed by concentric, fractional crystallization of the core, though many models may be possible.

BBM silicates, unlike those in GZ, contain very Al-rich chromite, which have only been observed in NWA 10019 [1], a pyroxene pallasite also containing plagioclase. The high Al indicates this sample was likely in contact with silicate melt when the chromite formed, as there is no other mineral reservoir in pallasites to contain that concentration of Al during cooling.

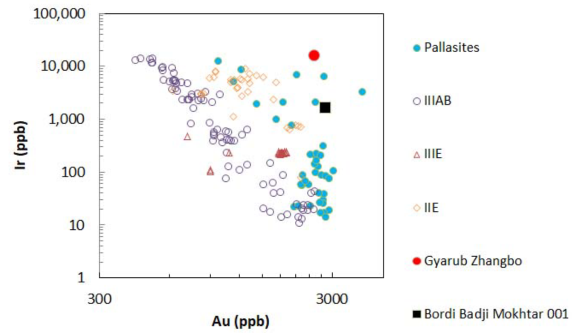

Figure 3. Ir vs AU plot showing the primitive nature of the metal in both BBM 001 and GZ.

Extraordinarily, the number of pallasite parent bodies now stands at a minimum of 12, assuming that all Main Group members are a single group (and not two or more groups, based on oxygen isotopes or olivine Fa content) [3], and that Zinder and NWA 1911 are paired [4]. The fact that all of these pallasites have, within a relatively small range, the same textural and petrologic characteristics, yet quite different chemical and isotopic compositions, argues in favor of a common differentiation/crystallization process on their respective parent bodies. Much like chondrites, where OC, CC, EC and the smaller chondrite classes have all experienced what is presumably a single, size sorting process among chondrules, CAIs and matrix within the early solar nebula, small differentiated mantle-cores in planetoids must have experienced essentially the same common differentiation and crystallization processes. Though the possibility exists that these processes could be related by some impact process or processes that occurred across the early solar system, it seems unlikely these dozen pallasite parent bodies resulted in their common textural and petrologic characteristics by experiencing twelve, separate “unique” geologic events.

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References: [1] J. S. Boesenberg et al. (2016) *LPS XLVII*, abstract #2297. [2] J. Gattacceca et al. (2023) The Meteoritical Bulletin No. 111, *Meteoritics & Planet. Sci.* [3] K. Ziegler and E. D. Young (2011) *LPS XLII*, abstract #2414. [4] J. S. Boesenberg and M. Humayun (2019) *LPS L*, abstract #1438.