

**FORMATION HISTORY OF THE BRACHINITES: PARTIAL MELTS FROM AN R CHONDRITE-LIKE PARENT BODY.** K. G. Gardner-Vandy<sup>1</sup>, D. S. Lauretta<sup>1</sup>, and T. J. McCoy<sup>2</sup>, <sup>1</sup>Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ, <sup>2</sup>Dept. of Mineral Sciences, National Museum of Natural History, Washington, DC (kgardner@lpl.arizona.edu).

**Introduction:** The primitive achondrite meteorites provide a unique window to the beginning of melting and differentiation on planetary bodies in the early solar system. The brachinites are a group of FeO-rich primitive achondrites that represent melting of a relatively FeO-rich body. In an effort to better understand the formation conditions and history of the brachinite parent body, we have extended our previous thermodynamic study of the formation conditions of the brachinites [1] to include more samples. Our study now includes Brachina, Allan Hills (ALH) 84025, Hughes 026, Northwest Africa (NWA) 3151, NWA 4969, and NWA 5400 (called “brachinite-like” by [2]). Here, we also discuss the implications of a series of 1-bar, gas-mixing, partial melting experiments of R4 chondrite LaPaz Ice Field (LAP) 03639. We performed these experiments to test our hypothesis that the precursor material to the brachinites was FeO-rich compared to other chondritic meteorites.

**Analytical Techniques:** Thin sections of the brachinites were either borrowed from the Smithsonian Institution (Brachina), the Antarctic Meteorite Collection at Johnson Space Center (ALH 84025), the Southwest Meteorite Laboratory (Hughes 026), or John Kashuba (NWA 5400), or were purchased from meteorite dealers (NWA 3151 and 4969). A thin section and large chip (2.7 g) of LAP 03639 was also obtained from the Antarctic Meteorite Collection at Johnson Space Center. We determined mineral compositions and analyzed experimental charges using the Cameca SX50 and SX100 electron microprobes at LPL.

**Thermodynamic Calculations:** We used the thermodynamic calculations we derived for the Tafassasset primitive achondrite in [3] to determine the oxygen fugacity ( $fO_2$ ) conditions under which each meteorite formed. We used the quartz-iron-fayalite (QIFa) and quartz-iron-ferrosilite (QIFs) systems (when applicable) to quantify the relationship between olivine and pyroxene FeO-content and  $fO_2$ . The equilibrium constants for the QIFa and QIFs equations relate  $fO_2$  to the activities of fayalite, ferrosilite, Fe-metal, and silica, and to temperature. See [1] and [3] for specific equations.

Temperature for the QIFa system was estimated using the olivine-chromite mineral thermometer. We located co-existing olivine-chromite pairs, and after ensuring homogeneity, used an average composition for each olivine and chromite grain. Final EMPA

chromite data was normalized using the method of [4] to calculate  $Fe_2O_3$  content by stoichiometry. The olivine and normalized chromite compositions were entered into a supplemental applet of MELTS to find the olivine-chromite temperature [5]. Temperature for the QIFs system was estimated for Hughes 026 and NWA 5400 using the two-pyroxene mineral thermometer. Because the pyroxene compositions are homogeneous, we used an average composition in the program QUILF to find the two-pyroxene temperature [6].

We calculated  $a_{Fe}$  from the average composition of individual metal grains in each meteorite. When we did not find metal in our thin section, we used values reported by [2]. We used the online MELTS calculator to calculate  $a_{Fa}$  and  $a_{Fs}$  for the average olivine and low-Ca pyroxene. As done in [3] and [7], we assumed  $a_{SiO_2} = 0.9$  and ran all calculations at 1 bar.

**Experimental Techniques:** Experiments were run in a Deltech gas-mixing furnace with an oxygen sensor and type R thermocouple, calibrated against the IW buffer and the melting point of Au (1064 °C), respectively. We have completed and analyzed five experiments, R1-R5. Experimental conditions are given in Table 1. The R4 and R5 experiments were run at 8 days and 2 days, respectively, to compare to the products of the 4 day runs. Oxygen fugacity was controlled with a 1-bar CO+CO<sub>2</sub> gas mixture. Charges were rapidly quenched in water. We choose  $fO_2$  values based on our analysis of the thermodynamic environment of brachinites, discussed below.

Label	Mass (mg)	Temp (°C)	Time (d)	log $fO_2$	$\Delta IW$
R1	221	1250	4	-12.3	IW-1
R2	242	1250	4	-10.3	IW+1
R3	158	1250	4	-11.3	IW
R4	79	1250	8	-12.3	IW-1
R5	90	1250	2	-12.3	IW-1

**Petrographic Results:** The brachinites are all medium- to coarse-grained, olivine-dominated (~80-95 vol %) achondrites with recrystallized, semi-equigranular texture. They contain minor clinopyroxene, chromite, sulfide, phosphate, and trace amounts of Fe,Ni-metal. Some contain orthopyroxene and plagioclase. Olivine is between Fa<sub>30</sub> and Fa<sub>36</sub>, and clinopyroxene is between Fs<sub>10</sub> and Fs<sub>14</sub>. Table 2 lists olivine, pyroxene, and chromite compositions used for thermo-

dynamic calculations. Sulfide composition is mostly troilite, although Brachina also has pentlandite. When measurable, metal in brachinites is  $\geq 20$  wt % Ni.

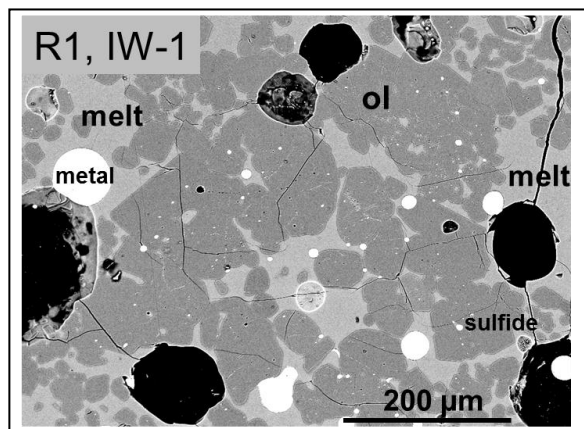
Meteorite Name	Olivine			Low-Ca Pyxn		High-Ca Pyxn		Chromite		
	Fa	Wo	Fs	Wo	Fs	Cr <sub>2</sub> O <sub>3</sub>	FeO	Fe <sub>2</sub> O <sub>3</sub>		
Brachina	32.3	-	-	38.9	14.0	53.6	27.0	2.65		
ALH 84025	33.4	-	-	43.0	11.3	58.0	28.7	0.21		
Hughes 026	34.1	3	28	46.3	10.2	52.4	27.4	0.83		
NWA 3151	35.6	-	-	45.5	10.7	53.0	27.6	0.41		
NWA 4969	34.5	-	-	46.8	10.0	52.4	27.4	1.00		
NWA 5400	29.9	2.2	24.5	44.0	9.8	57.4	27.5	0.42		

The starting material for our experiments, LAP 03639, is an R4 chondrite similar to known chondrites. It has chondrules and chondrule fragments  $\leq 1.1$  mm across. The matrix is made of olivine, pyroxene and plagioclase with sulfides containing 0-30 wt% Ni. Olivine is Fa<sub>39</sub>, low-Ca pyroxene is Fs<sub>6-26</sub>, high-Ca pyroxene is Fs<sub>10-12</sub>, and plagioclase is An<sub>5-13</sub>.

**Thermodynamic Results:** Our calculated values for each meteorite are given in Table 3 with the calculated olivine-chromite and two-pyroxene equilibration temperatures. Final  $fO_2$  values have an error  $\leq 10\%$ .

Meteorite	Ol-Chr	QIFa log	$\Delta IW$	2-Pyxn	QIFs log	$\Delta IW$
	Temp (°C)	$fO_2$		Temp (°C)	$fO_2$	
Brachina	1250 ± 19	-11.6	<b>-0.3</b>	-	-	-
ALH 84025	970 ± 46	-16.4	<b>-1.0</b>	-	-	-
Hughes 026	1038 ± 21	-15.4	<b>-1.1</b>	893 ± 84	-18.2	<b>-1.3</b>
NWA 3151	1054 ± 27	-15.0	<b>-1.0</b>	-	-	-
NWA 4969	1032 ± 15	-15.4	<b>-1.0</b>	-	-	-
NWA 5400	1028 ± 22	-15.5	<b>-1.1</b>	909 ± 26	-17.9	<b>-1.4</b>

**Experimental Results:** The R1-3 experiments resulted in significant silicate melting to the extent that homogeneous (Fa<sub>33.2±0.6</sub>, Fa<sub>39.4±0.2</sub>, and Fa<sub>39.5±0.7</sub>, respectively) anhedral to subhedral olivine as the only silicate mineral remaining (see figure). In the R4 experiment (8 days), a few skeletal orthopyroxene grains (Fs<sub>29</sub>Wo<sub>1.5</sub>) crystallized, poikilitically enclosing subhedral olivine grains. Olivine in R4 is homogeneous (Fa<sub>33.8±0.2</sub>), while olivine in R5 (2 days) is comparatively more heteroge-



neous (Fa<sub>35.4±1</sub>). Olivine grains for all experiments are surrounded by silicate melt with Mg# 27.7±0.7, 20.7±1.2, 22.3±0.7, 28.3±0.2, and 25.7±0.4, respectively for R1-R5. Significant S loss occurred in all but the R5 experiment, but there are several rounded Ni-rich sulfides in the R1-R4 charges. All charges have rounded Ni-rich metal. The only remnants of a chondritic texture are small regions with relict barred olivine grains in the R2 and R5 charges.

**Discussion:** Olivine-chromite temperatures for brachinites are all above the Fe,Ni-FeS eutectic (950 °C), which indicates that these meteorites have reached temperatures capable of melt generation. Likewise, these temperatures for all but ALH 84025 reach (within error) the ordinary chondrite eutectic of 1050 °C [8]. This is particularly true for Brachina, whose olivine-chromite temperature of 1250 °C is well within the range of basaltic melt generation. Calculated  $fO_2$  values for all brachinites except Brachina are  $\sim IW-1$ ; the calculated  $fO_2$  value for Brachina is  $\sim IW$ . In order to form the brachinites, with olivine of Fa<sub>32-36</sub>, between IW-1 and IW, a chondritic source that formed at an  $fO_2$  above IW and that also contains FeO-rich silicates is necessary. This would cause a relative reduction during the melting process to reach brachinite compositions. The R chondrites fit both requirements, having FeO-rich silicates (olivine is  $\sim Fa_{38-40}$ ) and formed at an  $fO_2$  between  $\sim IW$  and IW+3 [9]. Our experimental results, particularly those at IW-1, confirm that an R chondrite-like source could partially melt to produce residues with compositions matching those of brachinites. We acknowledge the constraint provided by the differing oxygen isotopic compositions of the R chondrites and the brachinites. We argue here that the parent composition of the brachinites was *like* the R chondrites and not the R chondrites themselves. Finally, our  $fO_2$  data also suggest what previous authors (e.g. [2]) have stated that either the brachinites formed on one heterogeneous parent body or that they represent formation by similar process on multiple parent bodies.

**References:** [1] Gardner-Vandy K. G. et al. (2009) *LPS XL*, Abstract #2520. [2] Day J. M. D. et al. (2012) *GCA*. In press. [3] Gardner-Vandy K. G. et al. (2012) *GCA*. In press. [4] Carmichael I. S. E. (1967) *Contr. Min. Pet.*, 14, 36-64. [5] M. Ghiorso, personal communication. [6] Anderson D. J. et al. 1993. *Comp. & Geosci.* 19, 1333-1350. [7] Benedix G. K. et al. 2005. *GCA*, 69, 5123-5131. [8] McCoy T. J. et al., *MESS II*, UA Press, pg. 733-745. [9] Righter K. and Neff K. E. (2007) *Pol. Sci.*, 1, 25-44.

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