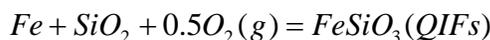
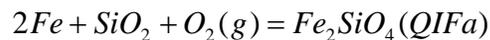


FORMATION CONDITIONS OF FeO-RICH PRIMITIVE ACHONDRITES. K. G. Gardner-Vandy¹, T. J. McCoy², and D. S. Laurretta¹, ¹Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ, ²Dept. of Mineral Sciences, National Museum of Natural History, Washington, DC (kgardner@lpl.arizona.edu).

Introduction: The primitive achondrites are meteorites with a chondritic bulk composition but a non-chondritic, recrystallized texture [1]. The meteorites that fall into this category (the acapulcoites, lodranites, winonaites, silicate inclusions in IAB and III CD irons, ureilites, brachinites, and several ungrouped meteorites) display a range of FeO-contents. The formation conditions of the FeO-poor primitive achondrites have been studied extensively (e.g. [2-4]). We have begun an extensive petrologic, geochemical and experimental study of the FeO-rich primitive achondrites in order to better understand their formation. Here, we follow the methodology of [5] and calculate the oxygen fugacity (fO_2) under which several FeO-rich primitive achondrites formed. We discuss the implications the results have on the thermodynamic conditions in which the FeO-rich primitive achondrite parent bodies evolved.

Analytical Techniques: We obtained thin sections of metal-bearing FeO-rich primitive achondrites Brachina (brach.), ALH 84025 (brach.), RBT 04239 (ungr.), LEW 88763 (ungr.) and ALH 84027 (LL7?) from the Meteorite Working Group and Tafassasset (ungr.) from the Southwest Meteorite Center for analysis. We determined mineral compositions using the Cameca SX50 electron microprobe at LPL. We use olivine, low- and high-Ca pyroxene, metal, and chromite compositions in our thermodynamic calculations.

Thermodynamic Calculations: We use the FeO content of olivine and pyroxene to determine the equilibrium fO_2 of these meteorites. Relationships between mineral composition and fO_2 are represented by:



The equations that relate the equilibrium constant (K) to temperature (T) in Kelvin are:

$$\log K_1 = \log \left(\frac{a_{Fa}}{a_{Fe}^2 \cdot a_{SiO_2} \cdot fO_2} \right) = \frac{29592}{T} - 7.61$$

and

$$\log K_2 = \log \left(\frac{a_{Fs}}{a_{Fe} \cdot a_{SiO_2} \cdot 0.5fO_2} \right) = \frac{29634}{T} - 7.60$$

These equations are valid between $773 \text{ K} \leq T \leq 1373 \text{ K}$. In these equations, a_{Fa} is the activity of fayalite, a_{Fs}

is the activity of ferrosilite, a_{Fe} is the activity of Fe metal, and a_{SiO_2} is the activity of silica.

We use the olivine-chromite and two-pyroxene mineral thermometers to determine closure temperatures for each meteorite. We determine olivine-chromite temperatures using MELTS [6] and two-pyroxene closure temperatures using QUILF [7], using 3-5 assemblages of contacting phases for each mineral pair. We assume $a_{SiO_2} = 0.9$ and calculate a_{Fe} using the average composition of individual metal grains in each meteorite. We use the MELTS calculator to calculate the activity of fayalite and ferrosilite [8-9]. All thermodynamic calculations are performed at 1 bar.

Results: We calculate two fO_2 values for each meteorite, one from QIFa and the olivine-chromite temperature, and one from QIFs combined with the two-pyroxene temperature. We report these oxygen fugacities in relation to the Fe-FeO (IW) buffer (Figure 1). Note that we did not calculate a QIFs fO_2 for ALH 84025 because we did not locate any low-Ca pyroxene in this sample.

Average mineral compositions for these meteorites are as follows:

Meteorite	Olv Fa	Pyroxene		Chromite		
		low-Ca Fs	high-Ca En Fs	Al ₂ O ₃	Cr ₂ O ₃	TiO ₂
Brachina	32.3	25.6	47.2 14.0	7.1	53.2	2.7
ALH84025	33.4	nd	45.6 11.3	7.1	56.9	1.3
RBT04239	24.4	20.7	47.1 8.0	5.5	55.3	2.9
Tafassasset	28.3	23.5	48.4 12.5	9.0	53.1	2.5
LEW88763	35.5	28.4	45.8 14.9	7.5	48.6	5.3
ALH84027	28.1	23.1	49.0 10.0	5.1	55.9	2.7

Discussion: Pyroxene closure temperatures for Brachina, ALH84025, Tafassasset and LEW88763 are above the ordinary chondrite eutectic (1050 °C) [10], which indicates that these meteorites may have generated a basaltic partial melt. The closure temperatures for these meteorites plus ALH84027 are also above the Fe-FeS eutectic (988 °C). These temperatures are consistent with a classification of primitive achondrite, having just barely reached temperatures capable of melt generation.

The olivine-chromite and two-pyroxene temperatures for individual analyses differ by values ranging from 50° to 344 °C (averages are given in table below). A small change in temperature may indicate rapid cooling. In this case, Brachina cooled more rapidly than ALH 84027 or RBT 04239.

Calculated fO_2 values range from IW-0.2 to IW-1.4 (see table). The fO_2 values increase with temperature,

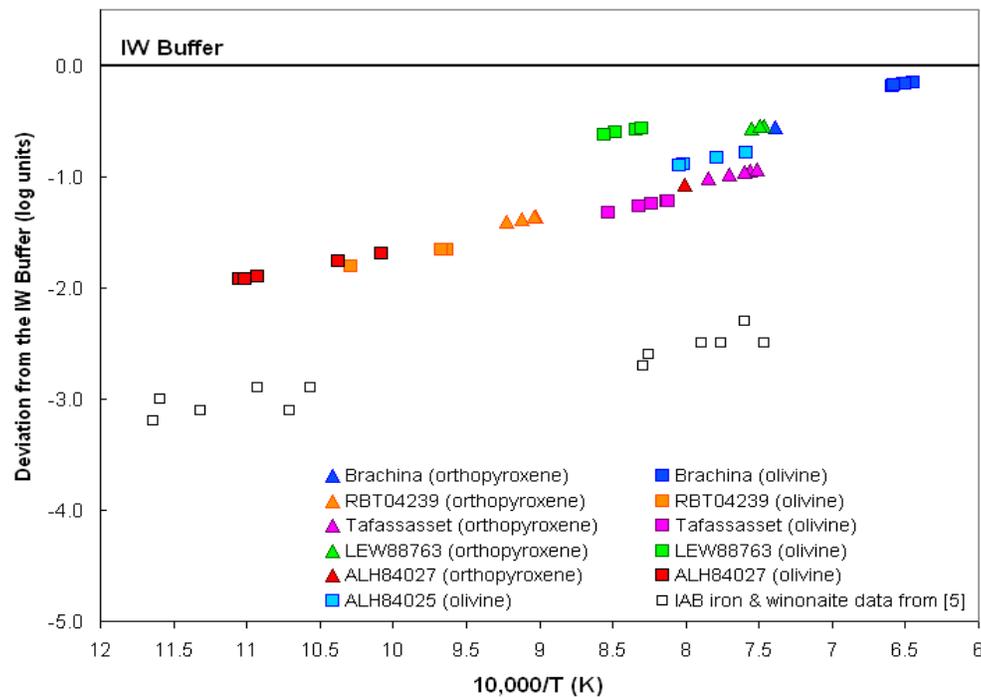
relative to the IW buffer, showing that oxidation state increases at higher temperatures. This result is consistent with the fact that both the QIFa and QIFs buffers approach the IW buffer at increasing temperature.

Samples that were heated above 988 °C are more oxidized, relative to those that experienced lower temperatures. This observation may indicate that metal loss through melt migration may result in a substantial increase in the oxidation state of the remaining silicate.

The oxidation state of the FeO-rich primitive achondrites could result from: 1) formation from oxidized chondritic precursors whose oxidation state was established in a high fO_2 region of the solar nebula (e.g. CK or R chondrites); or 2) formation from reduced chondritic precursors that accreted ice or hydrated silicates (e.g. CR chondrites).

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Meteorite	Type	ol-chr T (°C)	log QIFa fO_2	ΔIW	2pxn T (°C)	log QIFs fO_2	ΔIW
Brachina	brachinite	1259	-11.5	-0.2	1081 ± 55	-14.2	-0.6
ALH84025	brachinite	1000	-15.8	-0.9	na	na	na
RBT04239	UPA	742	-22.1	-1.7	826 ± 22	-19.7	-1.4
Tafassasset	UPA	937	-17.3	-1.3	1036 ± 45	-15.3	-1.0
LEW88763	UPA	911	-17.1	-0.6	1060 ± 40	-14.5	-0.6
ALH84027	LL7(?)	664	-24.5	-1.8	976 ± 43	-16.4	-1.1

UPA = ungrouped primitive achondrite

QIFa fO_2 is the fO_2 calculated from the Quartz-Iron-Fayalite system and the olivine-chromite T (K).

QIFs fO_2 is the fO_2 calculated from the Quartz-Iron-Ferrosilite system and the 2-pyroxene T (K).

ΔIW is the deviation of the calculated fO_2 from the iron-wustite buffer in log units.