EXPERIMENTAL PETROLOGY OF THE BASALTIC SHERGOTTITE YAMATO 980459: IMPLICATIONS FOR THE THERMAL STRUCTURE OF THE MARTIAN MANTLE.

H.A. Dalton[1], D.S. Musselwhite[2], W. Kiefer[2] and A.H. Treiman[2]; [1]Department of Geology, Arizona State University, Tempe, AZ (heatheradalton@yahoo.com), [2]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058 (musselwhite@lpi.usra.edu; kiefer@lpi.usra.edu; treiman@lpi.usra.edu).

Introduction: Yamato 980459 (Y98) is an olivine-phyric basaltic shergottite [1] composed of 48% pyroxene, 26% olivine, 25% mesostasis, and 1% other minerals. Unlike the other Martian basalts, it contains no plagioclase. Olivine in Y98 is the most magnesian of all Martian meteorites. Thus Y98 is believed to be the most primitive [2] and its composition may be the closest to a primary or direct melt of the Martian mantle. As such, it provides a very useful probe of the mineralogy and depth of its mantle source region. Toward this end, we are conducting crystallization experiments on a synthetic Y98 composition [3,4] at Martian mantle pressures and temperatures.

Experimental Methods: Experiments are being conducted using a Quickpress non-end-loaded piston cylinder apparatus with a pressure assembly comprised of a $BaCO_3$ cell, MgO internal parts, and a graphite sample capsule. Temperature is monitored with a W5Re/W25Re (C-type) thermocouple. Pressures range from 4 to 16 Kbars and temperatures from 1380°C to 1625°C for experiments conducted so far. Friction correction to the pressure is 1.8±0.1 Kbar below gauge. The experimental starting composition (Table 1) is an average of reported whole-rock values [3,4]. Oxides and carbonates were ground together with an agate mortar and pestle, then melted completely in a muffle furnace and reground to ensure homogeneity. Oxygen fugacity is controlled using the method of [5] whereby starting material with a preset Fe_2O_3 content [6,7] is loaded into a graphite capsule which influences the fO_2 by the oxidation of C to form CO_2 [5]. The Fe_2O_3 content of the starting material was preset by placing it in a CO/CO_2 gas mixing furnace at 800°C with log (fO_2) maintained at -14.85 ±0.1 for 90 hrs with a resulting Fe_2O_3 concentration of 1.07 ± 0.06 wt% (corresponding to an Fe^{3+}/Fe^{2+} ratio of 0.062)[6,7]. The resulting fO_2 for the piston cylinder runs is IW + 0.7 ± 0.1 log units [5]. Temperature and pressure ramps are done "hot piston out". That is, the assembly is first brought up to 10% above the run pressure, then ramped up to run temperature over 30 minutes. Once the run temperature is reached, the pressure is brought down to run pressure. At the end of the run the assembly is quenched isobarically. Run conditions are shown in Table 2. In addition, a 1-atmosphere melting experiment has been performed in a gas mixing furnace with fO_2 controlled at IW + 0.7±0.1 log units. Run products are analyzed using the Cameca SX-100 electron microprobe at NASA/JSC.

Results: Experimental results are listed in Table 2 and plotted in Figure 1. The inferred experimental liquidus or olivine-in line, and the pyroxene-in line are plotted. For comparison the liquidus calculated from the MELTS program [8] using the average bulk composition of [3,4] is also plotted.

Oxide	Y 980459 [3]	Y 980459 [4]	Target Comp	Comp as Weighed	Exp Glass Comp
SiO2	49.40	48.70	49.05	49.24	50.20
TiO_2	0.48	0.54	0.51	0.51	0.50
Al_2O_3	6.00	5.27	5.64	5.67	5.50
Cr_2O_3	0.71	0.71	0.71	0.71	0.66
FeO	15.80	17.32	16.56	16.63	15.82
MnO	0.43	0.52	0.48	0.48	0.49
MgO	18.10	19.64	18.87	18.95	19.35
NiO	0.03	0.03	0.03	0.03	0.01
CaO	7.20	6.37	6.79	6.81	6.97
Na_2O	0.80	0.48	0.64	0.64	1.09
K_2O	0.02	0.02	0.02	0.02	0.05
P_2O_5	0.31	0.29	0.30	0.30	0.36
S	0.07			0.00	0.01
FeS	0.19	0.26	0.23	0.23	
Total	99.54	100.15	99.81	100.00	101.00

Table 1: Experimental starting material. The second and third columns are published compositions of Yamato 980459 from [3,4]. The target composition is an average of these analyses. The last column is the composition of experiment Y 12-4, which produced only glass.

Sample	Pressure (kbar)	Temp (°C)	Duration (hours)	Results
Y 2	0.001	1455	2	glass
Y 5-24	3.5	1475	2	tr ol + glass
Y 5-25	3.2	1450	22	15% ol + glass
Y 5-27	3.1	1420	20	20% ol + glass
Y 5-2	3.2	1450	18	ol + glass
Y 7-28	5.8	1420	17	10% ol + pxn + gl
Y 8-19	6.9	1520	18	glass
Y 8-20	6.1	1490	22	olivine + glass
Y 8-21	6.2	1450	22	ol + pxn + glass
Y 12-6	10.9	1500	6	ol + pxn + glass
Y 12-17	10.5	1550	24	ol + glass
Y 12-29	10.7	1520	20	ol + pxn + glass
Y 12-31	10.7	1535	23	ol + pxn + glass
Y 16-18	15.9	1625	6	glass
Y 16-32	13.9	1590	24	glass

Table 2 – Run conditions and run products.

There is a notable difference between the experimentally determined liquidus and that calculated from MELTS. The calculated liquidus is at a higher temperature for a given pressure and has a greater slope than the experimentally determined liquidus (olivine-in line). The bulk composition of Y98 is outside the database of basalt compositions from which the MELTS algorithm is constructed, and thus may not be properly modelled.

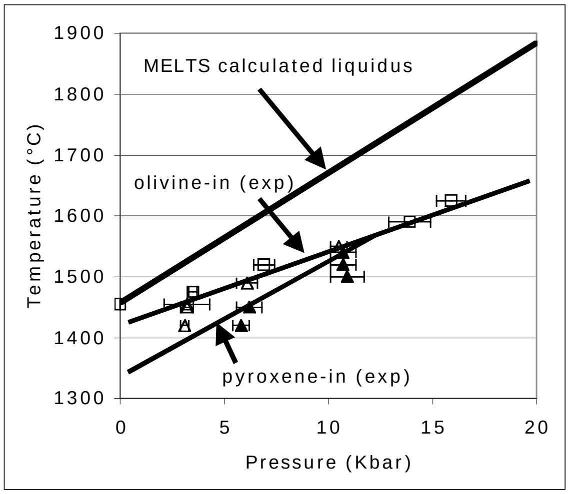

Figure 1: Experimentally determined phase relations for synthetic Yamato 980459 bulk composition. Open squares are experiments which produced only glass, open triangles produced olivine + glass, filled triangles produced olivine + pyroxene + glass. Experimentally determined olivine-in and pyroxene-in lines constructed from these results. MELTS [8] calculated liquidus plotted for comarison.

Implications for the Martian Mantle: The most important feature of the experimental liquidus relations for Y98 is the apparent convergence of the pyroxene-in and olivine-in curves at 11.5 to 12Kbars and 1560 to 1570 °C. This convergence needs to be confirmed by further experiments at this temperature and pressure range. However, if the olivine-in and pyroxene-in lines do indeed converge, it would indicate multiple saturation for the Y98 composition with separation from its mantle source at about 100 km depth. This conclusion is only possible if Y98 is a primary melt and not a cumulate.

The Mg#s for the experimental olivines range from 0.79 to 0.86. The high value is found in the experimental run products with the lowest abundance of olivine crystals and is the same as that for the cores of the olivines in Y98 [2]. The fact that the magnesium contents for the first formed experimental olivines and the cores of the natural olivines in Y98 are the same is strong evidence that Y98 is not a cumulate and therefore likely a primary melt.

Assuming that Y98 is a magma composition rather than a cumulate, the very high inferred melting temperature places significant constraints on the thermal state of the present-day martian mantle. We have extrapolated the melting curve to higher pressures and used the mantle plume melting calculations of Kiefer [9] to assess the conditions under which the Y98 melt could have formed. In these models, the primary variables that control mantle temperature are the concentration of mantle radioactivity and the temperature at the base of the mantle. If the martian mantle presently has 40% of the original Wanke and Dreibus [10] radioactivity remaining in the mantle, the temperature at the base of the mantle must exceed 2100 °C for the rising mantle plume to reach the measured Y98 melting temperature. If the martian mantle presently has 60% of the original Wanke and Dreibus radioactivity remaining in the mantle, the temperature at the base of the mantle must exceed 2030 °C in order to produce the observed Y98 melt. These temperatures are at least 200 °C higher than current estimates of the temperature of the martian core [11]. An alternative way to create high temperatures at the base of the mantle would be to have a layer at the bottom of the mantle that is strongly enriched in radioactive elements [10], although it is not yet known how much heating can be plausibly generated by this mechanism. Recent modeling of the martian gravity field [12] indicates that the lithosphere in Tharsis may be somewhat thinner than assumed in the earlier melting models. This would enhance the occurrence of pressure-release melting and permit the temperature at the bottom of the mantle to be somewhat cooler than indicated above. Our assessment of the trade-offs among these various mechanisms is on-going, although it seems likely that a combination of both basal heating of the mantle and thinning of the lithosphere will be necessary in any successful model for producing the Y98 magma.

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