EXPERIMENTS ON THE APOLLO 15 RED GLASS: NEW CONSTRAINTS ON MELTING DEPTH AND TiO_2 MELT CONTENTS OF ILMENITE SATURATED RESIDUES.

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Introduction: The Apollo 15 Red Glass represents an important end member in the broad compositional spectrum that exists in the lunar ultramafic glass suite [1]. This glass composition (at 13.8 wt. % TiO_2), and the Apollo 14 Black Glass (at 16.4 % TiO_2), represent the high TiO_2 extremes of the compositional spectrum covered by the lunar ultramafic glasses (from 0.26 to 16.4 wt. % TiO_2). Delano [2] investigated the high-pressure phase relations of the Apollo 15 Red Glass (15R) and Wagner and Grove [3] investigated the phase relations of the Apollo 14 Black Glass (14B). Even though these compositions are broadly similar, there are several important differences in the phase relations determined on these two samples. These differences have prompted us to repeat the 15R glass experiments with improved experimental techniques and re-evaluate the phase relations of the 15R glass. There are two major differences between the results of the 15R and 14B studies. The multiple saturation-pressures for olivine and low-Ca pyroxene on the liquidus were found to be at 2.5 GPa for the 15R glass [2] and at 1.5 GPa for the 14B glass [3]. Secondly, the TiO_2 content of the liquids saturated with ilmenite are 14.0 to 15.9 wt. % TiO_2 for the 15R glass and between 18.0 and 19.2 wt. % TiO_2 for the 14B glass. In addition, the experimental run times were only 1 to 2 hours in the 15R experiments, whereas, the 14B study used much longer run times of 24 to 84 hours for multiply saturated liquids. Wagner and Grove [3] were motivated to use these longer run times from the experience of Kinzler and Grove [4], who learned that run durations of > 24 hours were necessary to establish equilibrium in multiply saturated melts of terrestrial mantle peridotite.

Melt TiO_2 contents at ilmenite saturation: An important aspect of the 15R phase relations is that they represent the only experimental study on high TiO_2 glasses where ilmenite is a near-liquidus saturating phase. Beck and Hess [5] have recently calibrated ilmenite saturation as a function of temperature and pressure through experiments on a picritic glass analog composition. They find TiO_2 contents of 18 to 20 wt. % at 2 GPa and 1300 °C to 1350 °C. These TiO_2 contents are comparable to the 18.0 to 19.2 wt. % found by Wagner and Grove in their experiments on 14B glass. Both studies [3, 5] find higher TiO_2 contents than the 14.0 to 15.9 wt. % found by Delano in the 15R glass experiments.

Reanalysis of the 15R glass experiments: As a first step, we re-examined experimental charges run at 1.5 GPa-1300 °C, 1.75 GPa-1325 °C and 2 GPa-1350 °C by Delano in his original study [2]. These experiments all contain liquid + olivine + low-Ca pyroxene ± spinel ± ilmenite. The reanalysis of the quenched liquids are identical to those presented in [2]. We also examined the charges through back-scattered electron imaging and found that the analyzed glasses from the 1.75 and 2 GPa experiments were not in contact with the oxide phases (spinel ± ilmenite). In both charges the analyzed quenched melt is around the inner walls of the capsule and is in contact with only olivine + pyroxene. The oxides are isolated in patches surrounded by quenched areas in the interior and on the bottom of the capsules. Broad-beam analyses of quenched liquid next to the oxides in each of these charges yielded 18 wt. % TiO_2. Thus, the experiments were probably not run for a sufficient time to achieve equilibrium. Slow dissolution kinetics of disequilibrium olivine that formed metastably during the heating and pressurization step of the experiment are thought to be responsible for the persistence of olivine as a liquidus phase. New experiments on 15R glass under similar conditions show low- and high-Ca pyroxenes + oxides as the stable phases.

New experiments on 15R glass: We have begun experiments on the Apollo 15 Red Glass with a new starting material prepared according to the methods of Wagner and Grove [3]. Experiments have been carried out at 2 and 1.7 GPa using piston cylinder techniques described by [3]. Run times of 14 to 22 hours were used that resulted in considerably different phase relations. Experimental conditions were the same as those of Delano's experiments in which olivine + low-Ca pyroxene + spinel ± ilmenite were the stable phases. At 2 GPa and 1350 °C, we find that olivine is unstable and the liquid coexists with orthopyroxene + high-Ca clinopyroxene + ilmenite + spinel. At 1.7 GPa and 1320 °C, the phase assemblage is the same in a 22 hour long experiment. Analysis of all phases and a materials balance calculation show that the bulk composition of the charge remained constant. The TiO_2 contents of the glasses in these experiments are higher by ~ 1 wt. % than those of Delano and 8-10 wt. % ilmenite is present in the solid assemblage.

Multiple saturation and depth of origin of 15 R glass: The deep multiple saturation pressure of 2.5 GPa in the Apollo 15 Red Glass originally reported by Delano [2] thus appears to be an artifact of short experimental run times. The pressure of multiple saturation is probably closer to 1.5 GPa, similar to that reported by Wagner and Grove [3] for the Apollo 14 Black Glass. The TiO_2 contents of melts in equilibrium with olivine + orthopyroxene + ilmenite ± spinel also appear to be higher than those reported by Delano.

The new experiments should provide better constraints on models for the origin of the high-Ti ultramafic magmas and allow us to choose among the several competing hypotheses [6] for their origin. These experiments also call for a re-evaluation of the multiple saturation pressure and temperature determined by Green et al. (1975) [7] for the Apollo 17 Orange Glass (74220). The run times in Green's experiments were only 5 minutes and it is possible that similar kinetic factors influenced the results of these experiments. The high pressure multiple saturation pressures of the Apollo 17 Orange Glasses originally led Ringwood and Kesson to develop the magma ocean cumulate overturn hypothesis [8]. Perhaps with careful re-determination of the liquidus phase relations of these important glasses we will gain new insights into the processes of cumulate reshuffling that gave rise to these ultramafic magmas.

References:

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