ANALYSIS AND EXPERIMENTAL INVESTIGATION OF APOLLO BASALT SAMPLE 12032,366-18. A. C. Stadermann1,2, M. J. Krawczyński2, B. L. Jolliff2, and C. W. Hamilton1, 1Department of Planetary Sciences & Lunar and Planetary Laboratory, University of Arizona (acs@lpl.arizona.edu), 2Department of Earth and Planetary Sciences & McDonnell Center for the Space Sciences, Washington University in St. Louis.

Introduction: Apollo sample 12032,366-18 is composed of basalt with KREEP components and several mesostasis regions. These regions may have formed as interstitial melt pockets evolved into a field of silicate-liquid immiscibility (SLI), producing a silica-rich melt composition [1]. This sample was analyzed by 40Ar/39Ar and found to have evidence of partial degassing at 487±41 Ma and 688±10 Ma [2], which may indicate an origin from a younger impact than Copernicus, such as Kepler [1]. In this study, we analyze experimentally the crystallization of this basalt composition and the evolution of its residual melt. At issue is the origin of the silicic residual melt: was it by extreme fractional crystallization, metasomatism, or SLI?

Methods: To analyze both the sample, 12032,366-18, and experimental charges, we used a JEOL JXA-8200 Electron Microprobe at Washington University in the Department of Earth and Planetary Sciences, following standard procedures [e.g. 3]. We made X-ray maps of the sample (Fig. 1), including one of a mesostasis region (Fig. 2). Elements mapped were Si, Ti, Zr, S, Al, Cr, Fe, Mg, Ca, Na, K, and P. From these analyses, and those reported in [1], we calculated a bulk composition for the sample.

To investigate whether this bulk composition is representative of the whole-rock composition and to explore its crystallization systematics, we created a synthetic mix of oxides to represent the sample 12032,366-18 and performed low-P crystallization experiments. After pressing the mix into a pellet, we put this charge into a 1 atmosphere furnace at 1106°C for a designated run time (estimated liquidus T using MELTS software [4, 5]). After each experiment, which included mixtures of liquid and crystals, we then created a mixture of oxides to represent the composition of the glass in the preceding charge. In this way we simulated near fractional crystallization of the original bulk composition and constrained the composition of the mesostasis region of 12032,366-18 by maximizing the melt percent in each experimental drop in temperature. For each iteration the temperature was decreased slightly, and the run time of the experiment increased or remained the same. The run time was increased at lower temperature to allow crystals to grow large enough for microprobe analyses.

Results: Sample 12032,366-18 has olivine, pyroxene (pigeonite and augite), plagioclase, ilmenite, and chromian ulvöspinel as its major phases (Figure 1). Plagioclase and pyroxene grains are strongly zoned and the olivine is iron rich (Fo16-40) [see 1].

The mesostasis region is highly silica rich (Figure 2), with a silica content as high as 80 wt%. This region also contains significant concentrations of Al2O3, K2O, and Na2O (Table 1).

We did four main experiments, at temperatures of 1106°C, 1050°C, 1021°C, and 985°C. Run times were 20, 96, 257, and 148/261 hours, respectively. The final experiment was run in tandem, with one charge running for 148 hours and the other running for 261 hours.

Figure 1: X-ray map of 12032,366-18 with red as Al, green as Mg, and blue as Fe. Pyroxene is strongly zoned and plagioclase slightly less strongly. Ilmenite is dark blue in this image and olivine grains are lighter blue.

Figure 2: Back scatter electron (BSE) image of the mesostasis region in top left of Figure 1. Phases with a higher mean atomic number (Z) appear brighter. High Z phases in the mesostasis include zircon, tranquillityite, troilite. The mesostasis also includes barian K-feldspar.
The 1106°C charge contained olivine, plagioclase, clinopyroxene, and glass. The olivine was Fa85, while the plagioclase ranged from An85 to An81. The pyroxene was En32 Wo35. The glass was approximately 67 wt% of the charge and had a composition similar to the bulk composition of the charge, with slightly higher TiO$_2$, FeO, and P$_2$O$_5$.

In the 1050°C charge, we identified olivine, ilmenite, plagioclase, pyroxene, and glass. The olivine was more fayalitic in this charge than the 1106°C charge, Fa85. The plagioclase ranged from An87 to An81, becoming more albite than the previous charge. Pyroxene grains in this 1050°C charge became less magnesian and more ferroan. Glass composed 18 wt% of the charge and was enriched in SiO$_2$ and depleted in TiO$_2$, CaO, and MgO relative to the bulk composition of the charge.

Upon lowering the temperature to 1021°C, olivine no longer formed, while quartz/tridymite joined the crystal assemblage. Plagioclase ranged from An87 to An85, slightly more anorhinitic than the previous charge. Pyroxenes are strongly zoned, with ranges from Fs75 to Fs51. Ilmenite only made up 2.5 wt% of the charge, and quartz only 7.5 wt%. Glass composed 61 wt% of the charge, and had a composition depleted in SiO$_2$, Al$_2$O$_3$, P$_2$O$_5$, and Na$_2$O, and rich in FeO, CaO, and ZrO$_2$ relative to the bulk composition of the charge.

The final experiment, at 985°C, had Fe-rich olivine joining the crystalline assemblage, and clinopyroxene, plagioclase, ilmenite, merrillite, and two immiscible glasses (Figure 3). One of the glasses is FeO-rich, and the other is SiO$_2$-rich. The iron-rich glass had 45 wt% SiO$_2$ and 24 wt% FeO, whereas the silica-rich glass had 68 wt% SiO$_2$ and 7 wt% FeO. There was a portion of the glass that remained metastably miscible, indicating that the separation of the liquid was not at full equilibrium. Additionally, phosphate reached saturation in the liquids, allowing for the precipitation of merrillite.

Discussion: The changes in composition that we saw in the experimental charges are consistent with the zoning and major mineral phases that we see in sample 12032,366-18. This parallel between the Apollo sample and our experimental results shows that the bulk composition of 12032,366-18 is probably representative of the bulk melt from which the rock crystallized. The occurrence of SLI in our final 985°C experiment is supported by previous work that found SLI onset around 1000°C [6,7]. It was also found that P content is important for the SLI to occur [7], consistent with our findings.

The high silica mesostasis region in 12032,366-18 is indicative of possible SLI because such extreme silica enrichment is an unlikely end-stage melt. The mesostasis region would then represent the Si-rich immiscible liquid and the mafic counterpart would have been incorporated into late-stage pyroxene and olivine. The occurrence of late-stage SLI is supported by our 985°C experiment, and we did not find residual melts in the other experiments with intermediate silica, in fact, the residual melts followed a pattern of increasing FeO. The Si-rich immiscible liquid in our final experiment, however, still has significant FeO (7.6 wt%, so further solidification at this temperature or slightly lower is needed to test the final disposition and composition of the two silicate liquids).


Table 1: Average compositions in wt % for 12032,366-18 mesostasis and both liquids in the 985°C experiment. In 12032,366-18 mesostasis, MnO and MgO were both below the detection limit (0.03 wt%).

<table>
<thead>
<tr>
<th>Sample</th>
<th>SiO$_2$</th>
<th>TiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>BaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>P$_2$O$_5$</th>
<th>ZrO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12032,366-18 Mesost.</td>
<td>79.2</td>
<td>0.3</td>
<td>11.3</td>
<td>0.4</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.8</td>
<td>0.7</td>
<td>1.4</td>
<td>6.5</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Fe-liquid in 985°C Exp.</td>
<td>45.3</td>
<td>2.8</td>
<td>7.6</td>
<td>24.4</td>
<td>0.3</td>
<td>0.6</td>
<td>11.0</td>
<td>0.5</td>
<td>0.5</td>
<td>1.3</td>
<td>2.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Si-liquid in 985°C Exp.</td>
<td>68.1</td>
<td>0.9</td>
<td>11.4</td>
<td>7.6</td>
<td>0.1</td>
<td>0.2</td>
<td>3.7</td>
<td>0.4</td>
<td>0.8</td>
<td>5.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>