MAGMA VESICULATION IN APOLLO 15 MARE BASALTS: OBSERVATIONS AND THEORY.
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Vesicular fragments have been observed on the lunar surface ever since
Surveyor I landed in Oceanus Procellarum in 1966. Rocks with an apparent
vesicular structure were also observed in images from Surveyors III, V, VI,
and VII [1]. The vesicles in the fragments photographed by the Surveyors are
generally from 2 to 10 mm in length [1, p. 82-86]. In 1971, Apollo 15 landed
near Hadley Rille and three extremely vesicular samples from the landing area
were returned to Earth. These samples, 15016, 15529 and 15556, are all longer
than 10 cm and have masses greater than 900 g. Other vesicular rocks were
observed by the astronauts on the lunar surface, including one macrovesicular
boulder with cavities up to 10 cm in diameter [2]. On the basis of their
morphology, most of the highly pitted rocks observed and collected from the
lunar surface have been categorized as vesicular basalts [1,2]. Detailed
geochemical analyses of returned samples 15016 and 15556 indicate that they
are low-titanium olivine basalts [3]. From these observations and the apparent
abundance of vesicular basalts on the Moon, it is worthwhile to consider
the vesiculation of basaltic magmas under lunar conditions. An objective in
this study is to relate measurements of vesicularity in lunar basalts to com-
puted vesicle distributions derived from bubble dynamics in magmas.

Vesicles in two Apollo 15 basalt samples were measured from high resolu-
tion Lunar Receiving Lab (LRL) photographs; Table I summarizes the data for
samples 15529 and 15556, and Fig. 1 is a photograph of 15529. The length,
width, and distance to nearest neighbor were measured for every cavity visible
on the rocks' surface; the percentage of visible rock surface area occupied by
pits was also computed. Vesicle aspect ratios (W/L) and pit diameters (√WL)
were also determined. From these data, the average pit diameter and aspect
ratio can be derived. Table I demonstrates that vesicle diameters average
Q 2.4 mm in 15529 and Q 4.1
mm in 15556. Figure 2 displays the vesicle size-
frequency spectrum for each sample. Both distributions are somewhat gaussian.

Sato [4] has shown that reduction of graphite in lunar basaltic magmas
can produce enough CO to provide sufficient volatiles to explain the observed
vesicularity of lunar basalt samples. Using a bubble growth and dynamics
computer program initially developed by Sparks [5] and later extended by
Wilson and Head [6] and the present authors, it is possible to simulate vesi-
cle development in lunar magmas as a function of magma volatile species, con-
tent, rise rate, viscosity, density and temperature.

Using typical values for lunar basaltic magmas [6,7], simulations were
carried out until vesicles with diameters near to those measured in 15529 and
15556 were formed. Table II summarizes the results of some of the most
reasonable simulations. In all cases, the lunar magmas were calculated to
disrupt, either mildly near the surface, or more explosively at greater (> 50m)
depths. From these calculations (see Table II), it is apparent that lunar
basaltic magmas ascending at 0.20 m/s and having between 80 and 400 ppm of
dissolved CO match the observed vesicle distributions in lunar samples 15529
and 15556. The effect of varying magma viscosity from the value of 300 Poise
used in Table II changes the amount of dissolved CO required to produce 2-5
mm vesicles by less than a factor of two (using 30 and 3000 P instead of 300 P).
The effect of magma rise rate is more dramatic, and if lunar magmas were to
ascend at 1 m/s instead of 0.20 m/s or lower, over 1000 ppm CO would be re-
quired to produce the vesicularity observed in lunar samples. In addition,
high rise rate magmas would disrupt at greater depths, thus producing more

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explosive eruptions. On the basis of the measurements made from lunar samples 15529 and 15556, however, a magma rise rate of 0.20 m/s, a magma viscosity of 300 P, and 80-400 ppm of dissolved CO are the most reasonable values. These data are in agreement with Sato [4], who determined that 250-750 ppm CO gas could be produced in lunar basaltic magmas. Calculations pertinent to lunar eruption dynamics by Wilson and Head [6] support the results as well, and suggest that relatively non-explosive eruptions could have produced the Apollo 15 vesicular basalts.

In conclusion, our study indicates the viability of theoretical magma vesiculation simulations constrained by detailed observations of returned lunar basalt samples.


Figure 1: Apollo 15 vesicular olivine basalt sample 15529.

Figure 2: Size frequency distributions for vesicles measured on olivine basalt samples 15529 and 15556.

<table>
<thead>
<tr>
<th>15529</th>
<th>15556</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>olivine basalt</td>
</tr>
<tr>
<td><strong>Dimensions (mm)</strong></td>
<td>140x100</td>
</tr>
<tr>
<td><strong>Mass (grams)</strong></td>
<td>1531</td>
</tr>
<tr>
<td><strong>Vesicularity</strong></td>
<td>30%</td>
</tr>
<tr>
<td><strong>Vesicle size (mm)</strong></td>
<td>4.0 avg.</td>
</tr>
<tr>
<td><strong>Side measured</strong></td>
<td>North</td>
</tr>
<tr>
<td><strong>No. pits measured</strong></td>
<td>506</td>
</tr>
<tr>
<td><strong>Avg. length (mm)</strong></td>
<td>26.7</td>
</tr>
<tr>
<td><strong>Avg. width (mm)</strong></td>
<td>21.5</td>
</tr>
<tr>
<td><strong>Geom. mean (mm)</strong></td>
<td>24.0</td>
</tr>
<tr>
<td><strong>Aspect (W/L)</strong></td>
<td>0.696</td>
</tr>
<tr>
<td><strong>Surface area pitted</strong></td>
<td>35%</td>
</tr>
</tbody>
</table>

*From values measured by LSPET (Lofgren and Lofgren, 1981)[3]

<table>
<thead>
<tr>
<th>Weight fraction CO</th>
<th>50</th>
<th>80</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise rate (m/s)</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Viscosity (Poise)</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Depth (km)</td>
<td>0.35</td>
<td>0.54</td>
<td>1.08</td>
<td>1.59</td>
<td>0.65</td>
<td>2.07</td>
<td>2.20</td>
</tr>
<tr>
<td>Bub. diameter (mm)</td>
<td>3.3</td>
<td>5.3</td>
<td>13.4</td>
<td>26.7</td>
<td>6.7</td>
<td>52.7</td>
<td>66.0</td>
</tr>
</tbody>
</table>

Table I: Summary of data available on the two Apollo 15 vesicular basalts that were studied. Sample 15556 has an Mg # of 0.39, and is 45.7% SiO (no Qtz or Ne in CPI norm). No chemical analyses are available for 15529. Both samples are from near Hadley Rille (near station #a).

Table II: Results of bubble growth and dynamics simulations for lunar basaltic magmas. Values without * fit observed vesicle size distribution data from lunar samples 15529 and 15556 (Apollo 15). All simulations end in magma disruption at "final depth" (see column). Magma T = 1200 K, p = 3000 kg/m³.