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 computed vesicle distributions derived from bubble dynamics in magmas.

Vesicles in two Apollo 15 basalt samples were measured from high resolution 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 ($\sqrt{WL}$) were also determined. From these data, the average pit diameter and aspect ratio can be derived. Table I demonstrates that vesicle diameters average $\sim$ 2.4 mm in 15529 and $\sim$ 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 vesicle development in lunar magmas as a function of magma volatile species, content, 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 required to produce the vesicularity observed in lunar samples. In addition, high rise rate magmas would disrupt at greater depths, thus producing more

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.

References: 1) Surveyor Project, Part 2: Science Results (1968) JPL, Cal. Tech., 479 pp. 2) Swann G. A. et al. (1972) Apollo 15 PSR, NASA, 5-1 to 5-112. 3) Lofgren G. E. and Lofgren E. M. (1981) Lunar and Planet. Cont. 438, JSC, 418 pp. 4) Sato M. (1979) PLPSC 10, 311-325. 5) Sparks R.S.J. (1978) J. Volc. Geotherm. Res. 3, 1-37. 6) Wilson L. and Head J. W. (1981) Jour. Geophys. Res. 86, 2971-3001. 7) Housley R. M. (1978) PLPSC 9, 1473-1484.

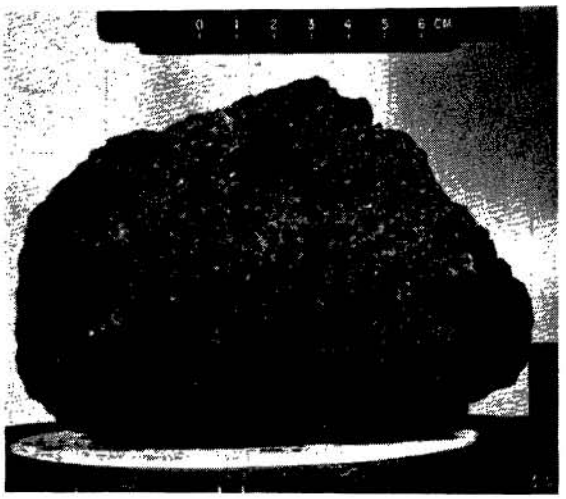

Figure 1: Apollo 15 vesicular olivine basalt sample 15529.

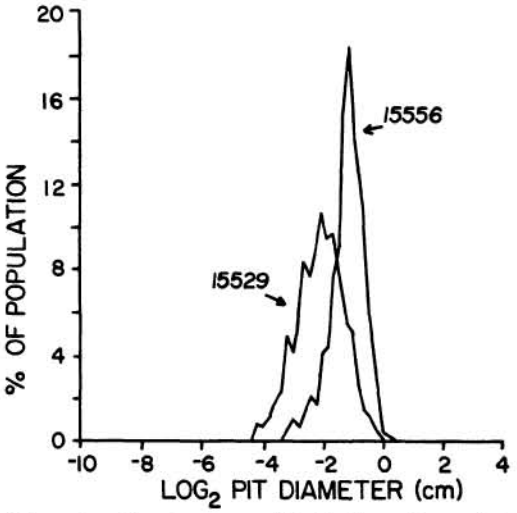

Figure 2: Size frequency distributions for vesicles measured on olivine basalt samples 15529 and 15556.

Type	15529 olivine basalt (weathered)	15556 olivine basalt
dimensions (mm)	140x100	130x110
mass (grams)	1531	1542
vesicularity+	30%	80%
vesicle size+ (mm)	4.0 avg.	2-10
side measured	North	top-bottom
no. pits measured	506	577
avg. length (mm)	26.7	47.0
avg. width (mm)	21.5	36.3
geom. mean ($\sqrt{LW}$) (mm)	24.0	41.0
aspect (W/L)	0.698	0.712
surface area pitted	35%	81%

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

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_2 (no Qtz or Ne in CIPW norm). No chemical analyses are available for 15529. Both samples are from near Hadley Rille (near station 9a).

weight fraction CO (ppm)	magma rise rate (m/s)	magma viscosity (Poise)	depth nucl. (km)	final depth (m)	final bubble diameter (mm)
50	0.20	300	0.35	3.3	1.6
80	0.20	300	0.54	5.3	2.0
100	0.20	300	0.65	6.7	2.2 *
200	0.20	300	1.08	13.4	3.2
400	0.20	300	1.59	26.7	4.7 *
600	0.20	300	1.88	39.8	6.2
800	0.20	300	2.07	52.7	7.9
1000	0.20	300	2.20	66.0	10.1

Table II: Results of bubble growth and dynamics simulations for lunar basaltic magmas. Values with "*" 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, ρ = 3000 kg/m^3.