equal to 1 mm^2, stresses on the order of 10^8 N/m^2 were exerted on the surfaces of the two immobile rocks (Moore et al. 1987). The fact they did not chip, scratch, or spall indicates that the rock surfaces are strong and are not covered with mechanically weak weathering rinds, although more competent alteration fronts or rinds may be present. Mass estimates obtained for the three successfully pushed and displaced rocks are given in Table 2.

Table 2. Mass, volume, and density estimates

Rock name	Weight (N)	Mass (kg)	Volume[a] ($\times 10^3$ cm^3)	Bulk density (g/cm^3)
Badger	24 ± 12	6.4 ± 3.2	3.0 ± 0.6	2.1 ± 1.1
Bonneville	22[b]± 11	5.9 ± 2.9	2.3 ± 0.5	2.6 ± 1.4
Notch	29 ± 14	7.8 ± 3.9	3.3 ± 0.6	2.4 ± 1.3

[a]Ellipsoid shapes assumed. [b]Value given in Moore et al. (1978) page 12; rock displaced upward rather than pushed back.

Rock volumes

The Viking Team made volume estimates of the rocks using the twin cameras of the Viking lander, which provided stereo coverage of the sampling field. Topographic profiles were manually generated with the assistance of image processing software (Liebes and Schwartz 1977). High-resolution vertical slices and contour maps of the sample field were compiled to create shape models of each of the candidate rocks. These topographic data was used to create plaster of paris and epoxy resin models for several candidate rocks and were used with the full-scale mock lander (Science Test Lander) in a sandbox to develop the pushing technique (Moore et al. 1978). Unfortunately, neither the model rocks nor the detailed topographic data used to create them were archived. We therefore approximated the rocks' volumes using the spatial dimensions of rocks in the catalogue compiled by Moore and Keller (1990) and published lower resolution topographic data (Liebes 1982; Wu and Schafer 1982). Even if the original topographic data used by the Physical Properties Team had been available, the volume estimates would still be subject to some uncertainty (~10-20%) due to the fact that rear portions of the rocks were out of view of the lander's cameras. The estimated volumes were combined with the mass estimates to obtain the bulk densities of the rocks given in Table 2.

Rock surface textures

Most rocks at the Viking 2 landing site are covered with small pits or vesicles. The exact mode of origin of this pitted surface texture has been a matter of some debate. Suggestions about the origin of the pits can be grouped into two general categories: primary textures and secondary textures. A primary surface texture would mean that the pits are vesicles—exsolved bubbles of volatiles quenched in a glass—implying that the rocks are either vesicular volcanic rocks (*e.g.*, Mutch et al. 1977) or vesicular impact melt breccias (Schultz and Mustard 2004). Alternatively, the surface texture has been suggested to be a secondary erosional texture formed by eolian abrasion (McCauley et al. 1979) or by chemical weathering (*e.g.*, Allen and Conca, 1991).

The distinction between a primary and a secondary pitted texture has important consequences for a rock's density. In the former case, the presence of vesicles or void spaces in a rock interior significantly lowers the overall density. If the pitted textures are limited to exterior surfaces, however, then the pits have a minimal effect on the bulk density. To accurately estimate the percentage of pits covering each pushed rock, we created super-resolution image composites after the method of Parker (1998) (Figures 2b-d). The resulting estimates are given in Table 3.

Table 3. Rock surface area covered by pits

Rock name	Vesicularity (%)
Badger	31 ± 2
Bonneville	24 ± 2
Notch	16 ± 1

Results

The uncorrected bulk densities reported in Table 2 are all ≤2.6 g/cm^3. To assess the type of Martian rock that corresponds to a given density, we use Martian glass compositional data from a series of crystallization experiments run on a primitive SNC basaltic starting composition by Minitti and Rutherford (2000). Glass densities were calculated according to the procedure outlined by Spera (2000) using standard Martian surface temperature and pressure (222 K, 6 mbar).

Comparing the bulk densities to the first-order predicted Martian rocks densities in Figure 3, it is evident that this

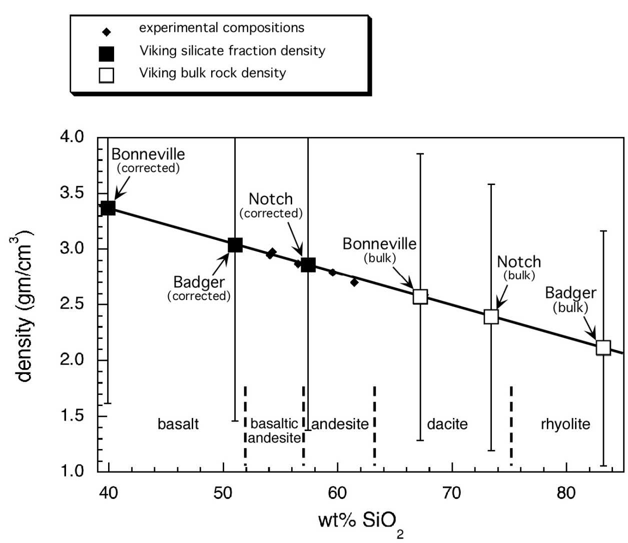

Figure 3. Density versus SiO_2 wt.% plot for Martian glasses. Trend line is a linear least-squares fit to data from anhydrous crystallization experiments using a primitive SNC basaltic starting composition (Minitti and Rutherford 2000). Solid diamonds represent the experimental data, open squares represent the bulk densities of Viking rocks, and filled squares represent the density of the silicate portion of the rocks (after correcting for rock vesicularity). Error bars indicate uncertainty dominated by coarse force resolution of sampling arm. Volcanic rock classification from Le Bas et al. (1986) TAS diagram, assuming low total alkalis.