should be in a reduced gravity field. Possible effects due to local topography have not yet been fully analyzed.

The 480-g shroud, which is a hollow cannister with metal plate tip, produced a crater about 1 cm deep and 9 cm in diameter by the displacement of rocks and the ejection of fine debris. Unlike the case in Earth-based tests, the shroud ricocheted from the field of view in the image shown in Fig. 1.

Latch pin impact. The boom latch pin of the surface sampler, which failed to release at the scheduled time, ultimately fell to the martian surface (see Fig. 3) from an estimated height of between 1.0 and 0.9 m in the morning of sol 5 (*11*). The velocity at impact from this height at the surface of Mars is between 2.7 and 2.6 m/sec and is equivalent to a fall height near 0.36 m on Earth. The pin, a slender (8.2 cm long, 0.6 cm in diameter, and 11.3 g) rod, impacted on an end with two roller bearings and then fell over toward the spacecraft. Upon impact a small circular crater about the size of the roller bearings was produced (see Fig. 5) by the ejection of dark, very fine-grained material (probably silt size) to distances of 2.4 cm from the crater center where the rollers hit. The remainder of the pin fell toward the spacecraft, producing an elongate depression by the ejection of dark material to distances of 1.5 cm from its axis. The pin now rests in this depression (Fig. 5).

Although the exact orientation of the pin at impact is unknown, the crater, depressions, and their ejecta are consistent with those of terrestrial materials with very low cohesions, a small grain size, and reasonable densities (1.2 to 1.7 g/cm^3).

Surface temperature measurements. A temperature sensor (thermocouple) attached to the inboard side of footpad 2 was used to measure ambient temperature during the parachute phase of the landing (*12*). Its survival depended on a soft landing, which indeed was the case. Temperature readings are being recorded periodically during the day and night. Since the sensor cannot be seen directly, it is not known whether the sensor is covered with surface material. Images of the sensor will be obtained by use of a mirror on the surface sampler later in the mission to aid in the interpretation of the data.

This first report on the physical properties of the martian surface must be considered preliminary. More refined measurements are to be made, based on stroke gauge extension, footpad penetrations, stereo images of the landing site area, and other new data such as motor currents during trenching and comminution. As these data are obtained, better values of the surface properties can be reported.

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4. Laboratory tests were carried out at the Langley Research Center under martian atmospheric conditions with different soil models.
5. The lunar nominal soil model is an artificially prepared soil having a particle size distribution based on screen analysis provided by the results of the Apollo 11 mission. The technique employed in the fabrication of the lunar nominal model was to take volcanic rock aggregate in the size range of from 5 cm to pan size from Table Mountain, Golden, Colorado, and grind it in an allochthonous mill charged with a few steel-alloy balls. The fine fraction of the model was separated in discrete size fractions by an air classifier. The coarse-sized particles were separated by screening. The crushed rock product was then blended in individual 55-gallon (208-liter) covered steel drums to achieve the desired particle size distribution for each drum.
6. The dune sand soil model is a natural occurring dune sand of volcanic origin. The material was collected near Sunset Crater, Arizona, in the Elden Ranger District of the Coconino National Forest.
7. We prepared the lunar nominal soil originally by placing it in 7.5-cm layers in the containers. Each layer was rolled several times with a garden roller to compact it. The final bulk density obtained for the material was in the range 1.7 to 1.8 g/cm^3.
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9. Data were obtained by the lander performance analysis group from the inertial platform data which remained operational for 15 seconds after touchdown.
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11. The normal sequence was modified because of the failure of the boom latching pin to drop out as the boom extended. The boom was subsequently commanded to extend farther, resulting in normal operation and the ejection of the pin.
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The Viking Landing Sites: Selection and Certification

Abstract. *During the past several years the Viking project developed plans to use Viking orbiter instruments and Earth-based radar to certify the suitability of the landing sites selected as the safest and most scientifically rewarding using Mariner 9 data. During June and July 1976, the Earth-based radar and orbital spacecraft observations of some of the prime and backup sites were completed. The results of these combined observations indicated that the Viking 1 prime landing area in the Chryse region of Mars is geologically varied and possibly more hazardous than expected, and was not certifiable as a site for the Viking 1 landing. Consequently, the site certification effort had to be drastically modified and lengthened to search for a site that might be safe enough to attempt to land. The selected site considered at 47.5°W,22.4°N represented a compromise between desirable characteristics observed with visual images and those inferred from Earth-based radar. It lies in the Chryse region about 900 kilometers northwest of the original site. Viking 1 landed successfully at this site on 20 July 1976.*

The initial plans for site selection included the identification of a prime and a backup landing site for each spacecraft (*1*), and an additional pair of sites to be used as a contingency, selected primarily on the basis of safety. Areas near the prime and backup sites for the Viking 1 lander were first observed by Earth-based radar in 1967 and in the period from May to July 1976—about the time of insertion of the spacecraft into orbit about Mars. The northerly sites considered for the second lander are not observable by radar at any time, and are considered therefore as somewhat more of a risk. The third pair of sites was selected where they could be readily observed by Earth-based radar, and could be used in the event that the first landing was unsuccessful. These preselected site locations are shown in Fig. 1; the Viking 1 A sites were located at about 20°N latitude; for the Viking 2, the prime and backup B sites were at about 44°N latitude while the alternate C sites were at about 5°S latitude. The A1 site was located at the place where the largest Mars channel complex debouches onto Chryse Planitia. It was therefore considered to be the best area to observe where water and possibly near-surface ice had occurred in large quantities in the past—the optimum place to look for complex organic molecules. The B1 site was selected at the latitude of maximum water vapor concentration, the optimum place to land the biology experiment; at this longitude the two orbiters could provide relay support to either lander, and the second orbiter could observe the polar region. The C1 and C2 sites were selected primarily on the basis of their radar signatures, which indicated that they were relatively smooth. These sites also have acceptable characteristics in the Mariner 9 imagery and allow observations to be made of the polar regions.

The overall sequence of the major site certification decisions is shown in Fig. 2. Important points and mission rules were:

1) The A1 site area would be observed visually from orbit (*2*) and by the X-band Goldstone and S-band Arecibo radars (3.5 cm and 12.5 cm wavelength, respectively) from 29 May through 10 June 1976 (*3*). The A2 site could not be observed with the orbiter cameras prior to the decision to land or not land at A1, but could be studied by both Goldstone and Arecibo radars 10 June through 15 June.

2) The Viking 1 lander would land at A1 unless new information shows A1 to be unsafe.

3) Lander 2 would land at B1 unless (i) lander 1 failed, or (ii) lander 1 is delayed so that success has not been determined at the time when lander 2 must be committed, or (iii) new information shows B1 to be unsafe or of inadequate scientific interest.

4) If lander 1 either failed or was delayed, or new information caused B1 to be rejected, the lander 2 would be targeted to the best available site based on all data available.

5) The C sites at about 5°S were observed by the X-band radar at Goldstone and the S-band radar at Arecibo during the winter of 1975–1976; hence the data were available and the sites selected in March 1976, well before the first spacecraft encountered Mars 19 June 1976.

6) Photographs of the B1 and C1 sites would be taken before the A1 landing to obtain a broader base of Mars data to aid the interpretation of the A1 results as well as to provide additional information for choosing between the 44°N and 5°S latitudes for Viking 2.

Analysis techniques. The orbital photographs were made into uncontrolled mosaics from the rectilinear (tilts not removed) images. Then orthographic mosaics adjusted to the scale of 1 : 1,000,000 were made. Geologic and terrain maps were compiled, and hazard probabilities were entered into the computer so that statistics based on various approaches could be made. Crater counts were computed to compare subunits of areas studied. There were also comparisons of areas with each other and with Surveyor (automated spacecraft) landing sites on the moon. Contour maps and terrain statistics were computed for parts of the area by means of analytic photogrammetric techniques. The final maps were compiled after control point nets were computed. Lastly, photometric roughness maps were made—so-called digital number variance maps—that quantified brightness variations. Ellipses were then fitted to these maps with the radar interpretations being taken into account.

Results, decisions, and effects on mission plans. The prime site radar observations were completed on 10 June 1976; on 19 June 1976, Viking 1 was placed in its orbit about Mars. As a result of the

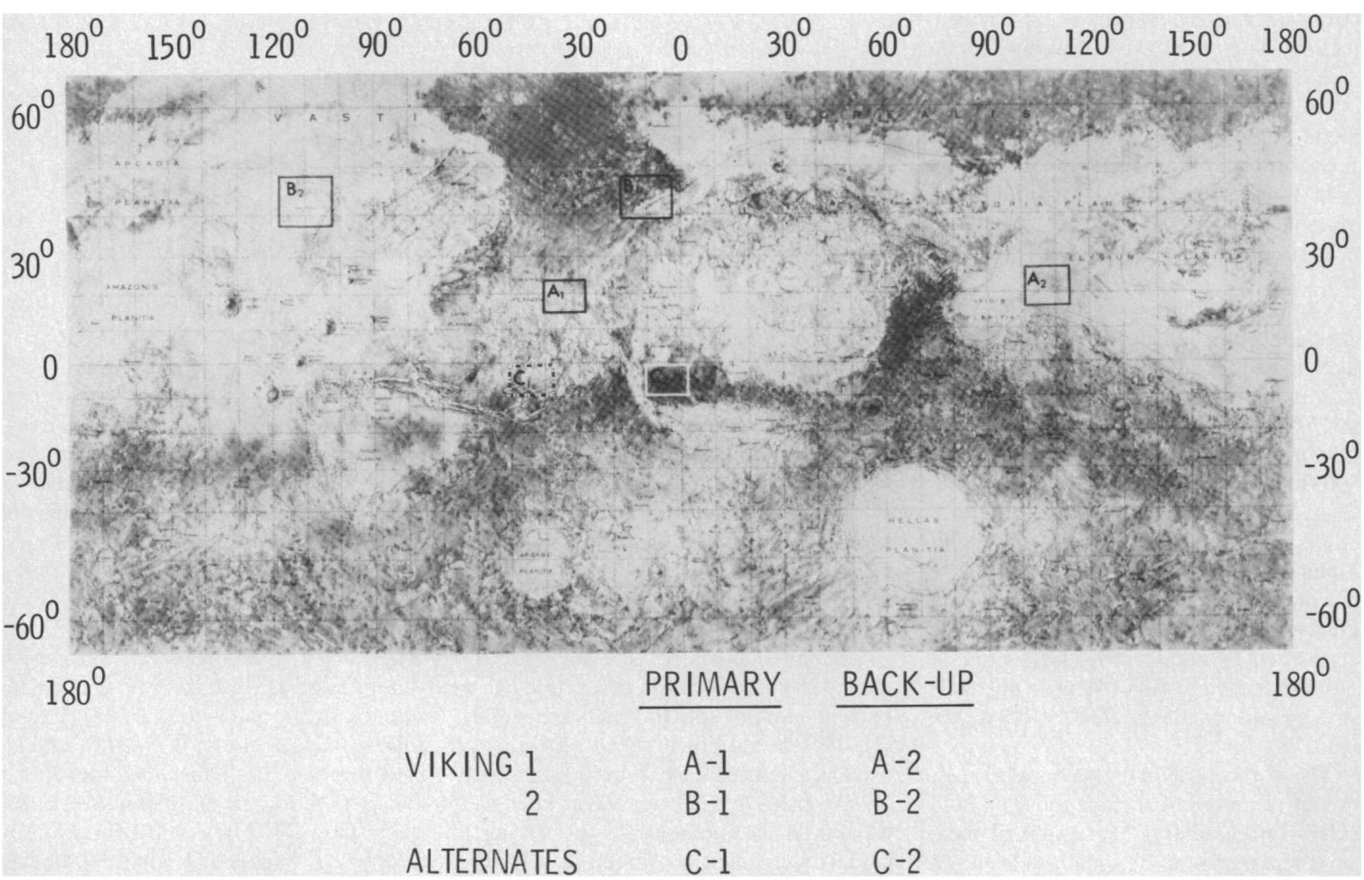


Fig. 1. Viking landing sites.

spacecraft observations taken through orbit 6 the original A1 area was rejected on 26 June primarily on the basis of the orbital imaging data, which indicated that the terrain was unexpectedly complex. Additional coverage on orbits 8 and 10 to the northwest of the original A1 area was planned, as shown in Fig. 3. Consideration was given to going to the A2 site at this time, but the three Mariner 9 high-resolution images in that area indicated the presence of knobs and small craters in that area, while the radar observations showed the area to be relatively smooth on a small scale. But there was concern that blocks, not detected by the radar, might be abundant at that location. By 1 July, the coverage from orbits 8 and 10 had been obtained and that area appeared visually satisfactory. A tentative decision was made to go to a new site "A1NW" at 23.4°N and 43.4°W, and at the same time obtain additional Arecibo radar data on 2, 3, 4, and 5 July, at 23°N. This site was selected by adjusting the 99 percent landing ellipse to avoid the hazardous features visible in the orbiter images. Radar data from Arecibo were obtained, and reviewed on 7 July. The radar observations showed the A1NW location to be an area of anomalous radar scattering, interpreted as a surface that was very rough on the scale of the lander or of very low density (or both), although the pictures looked the smoothest of any examined.

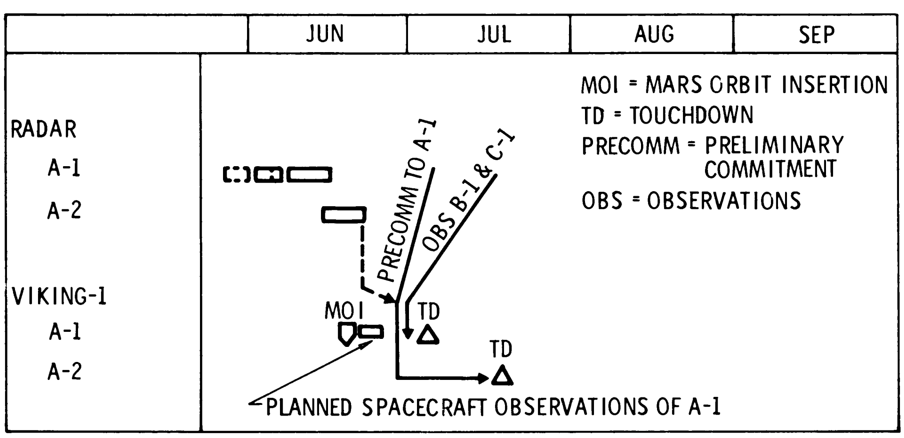
It therefore was decided to continue the search to the west in the hope of locating a site in an area of more satisfactory radar characteristics, and one that was also free of terrain hazards visible in the pictures. Additional coverage was planned on orbits 20 from 43° through 51°W, and on orbit 22 from 48.6° through 56.6°W (Fig. 3). On 11 and 12 July, the images obtained on orbits 20 and 22 were reviewed, and three possible ellipses with acceptable visual terrain were selected as follows:

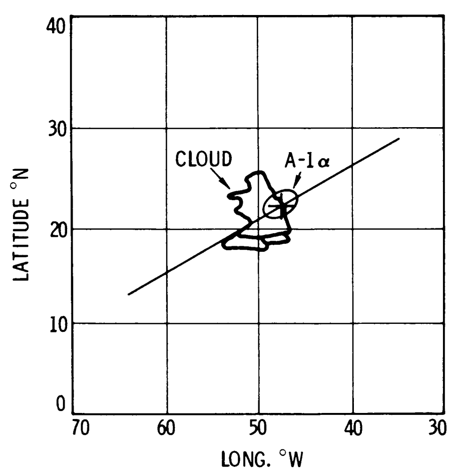
A1α	22.4°N	47.5°W
A1β	22.5°N	49.0°W
A1γ	22.2°N	51.0°W

The A1α, also called A1WNW, was selected as a compromise between hazards visible in pictures, chiefly impact craters with their associated blocks and small-scale surface properties, based on radar interpretation. The landing was rescheduled for 20 July 1976. The A1α site contained two moderate sized fresh impact craters whereas A1γ contained eight larger fresh impact craters. Farther west the incised channels reappeared on the basin slope and large fresh impact craters are more abundant. The 1967 data indicated that this area is smooth. But the 1976 Arecibo coverage did not include this region.

An orbital trim maneuver, originally planned for 16 July to align the orbit over the 50°W longitude coverage area, was advanced 2 days in order to optimize conditions for a landing at 47.5° longitude. This maneuver was successfully performed on 14 July 1976. On 17 July 1976, 78 stereoscopic images of the final landing ellipse were obtained. These pictures showed slightly increased crater counts in the A1α area, due to an improved viewing geometry. They will also provide the material for the postlanding topographic and geologic maps of the area.

High-altitude observations of the A1α area on 18 July show a large diffuse cloud extending into the southwest half of the dispersion ellipse, Fig. 4, giving some concern that a dust storm might be starting in that area. A cloud was seen previously in that area on 9 July, but had cleared by 11 July. The cloud observed on 18 July was tentatively classified as a condensate probably formed by radiation cooling on the basis of appearance at several wavelengths. Its velocity was





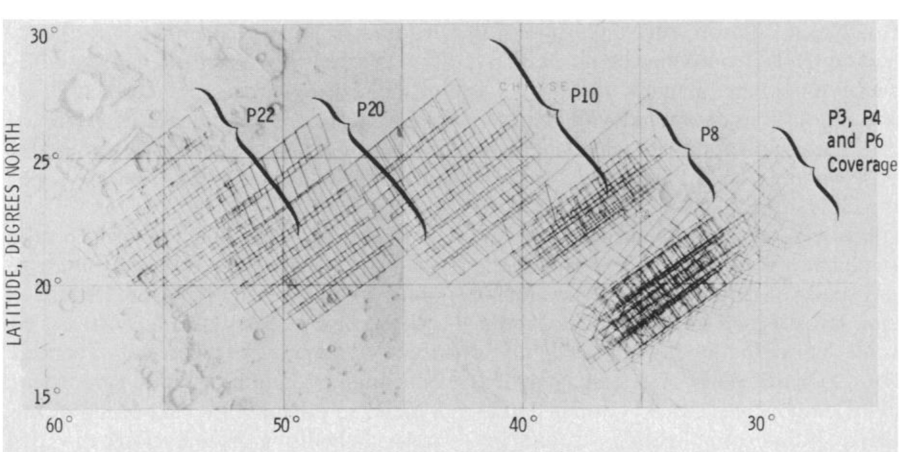


Fig. 2 (top left). Viking site certification timeline. Fig. 3 (bottom left). Viking 1 VIS observations in Chryse Planitia. Fig. 4 (above). Location of white cloud seen on 18 July high-altitude observations.

measured to be less than 3 meters per second. The low values of wind reinforced the conclusion that the cloud was a condensate. Consequently, it was believed that this feature would not interfere with either the lander entry or post-landing imaging. The successful landing occurred on 20 July 1976 at 5:12 a.m. PDT.

The lander pictures showed abundant blocks consistent with the presence of small impact craters in the vicinity. It is therefore suggested that the high radar reflectivity indicates that bedrock is near the surface and many blocks can be ejected by the impact. Such areas should be carefully considered prior to acceptance as landing sites in the future. Further discussion of both the visual and radar characteristics is presented by Carr *et al.* (*2*) and Tyler *et al.* (*3*), respectively.

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3. G. L. Tyler, D. B. Campbell, G. S. Downs, R. R. Green, H. J. Moore, *ibid.*, p. 812.
4. The Viking Site Certification effort represented the combined efforts of nearly the entire Viking flight team. Some of those involved in the almost daily activities of the landing site staff include: M. J. Alazard, D. L. Anderson, W. A. Baum, K. Blemann, J. Boyce, G. A. Briggs, D. B. Campbell, M. H. Carr, H. Craft, J. A. Cutts, D. M. Davies, G. S. Downs, F. Drake, V. R. Eshleman, C. B. Farmer, W. Farrell, E. A. Flinn, J. Gliozzi, R. M. Goldstein, J. D. Goodlette, R. Greeley, R. R. Green, J. E. Guest, R. Hargraves, S. L. Hess, N. Hinners, W. Jakobowski, H. H. Kieffer, L. Kingsland, K. P. Klassen, H. P. Klein, R. S. Kraemer, C. Leovy, P. T. Lyman, T. Z. Martin, H. Masursky, W. H. Michael, H. J. Moore, II, E. C. Morris, T. A. Mutch, J. F. Newcomb, F. T. Nicholson, W. J. O'Neil, T. Owen, F. D. Palluconi, J. D. Porter, R. J. Reichert, C. Sagan, G. Schaber, R. A. Simpson, R. W. Sjostrom, B. A. Smith, C. W. Snyder, L. Soderblom, G. A. Soffen, T. E. Thorpe, P. Toulmin, III, G. L. Tyler, E. D. Vogt, plus several hundred or so others at JPL and the U.S. Geological Survey at Flagstaff, Arizona, who also supplied brains and hands to make the system work. J. S. Martin, Jr., A. T. Young, and B. G. Lee were the recipients of the recommendations of the landing site staff and patiently endured our long march northwest across Chryse Planitia.

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Radar Characteristics of Viking 1 Landing Sites

Abstract. *Radar observations of Mars at centimeter wavelengths in May, June, and July 1976 provided estimates of surface roughness and reflectivity in three potential landing areas for Viking 1. Surface roughness is characterized by the distribution of surface landing slopes or tilts on lateral scales of the order of 1 to 10 meters; measurements of surface reflectivity are indicators of bulk surface density in the uppermost few centimeters. By these measures, the Viking 1 landing site at 47.5°W, 22.4°N is rougher than the martian average, although it may be near the martian average for elevations accessible to Viking, and is estimated to be near the Mars average in reflectivity. The A1NW site at the center of Chryse Planitia, 43.5°W, 23.4°N, may be an area of anomalous radar characteristics, indicative of extreme, small-scale roughness, very low surface density, or a combination of these two characteristics. Low signal-to-noise ratio observations of the original Chryse site at 34°W, 19.5°N indicate that that area is at least twice as rough as the Mars average.*

The surface properties of Mars determined by Earth-based radar were one of several factors that were considered in selecting the Viking 1 lander site. Estimates were made of surface roughness and density based on spectral broadening and the strength of centimeter-wavelength radio echoes returned from Mars.

Radar observations have been conducted at each Mars opposition since 1963. Since 1968 a combination of geometrical constraints and system sensitivity limitations have restricted these measurements to Mars latitudes south of 15°N, that is, below the planned landing areas of both the first and second Viking missions. Recent improvements at both Arecibo Observatory (*1*) and Goldstone Tracking Station (*2*) made observations feasible at 20°N in May and June 1976 and at 23°N from Arecibo in July. At these times the planet's distance was about 2 A.U. as compared with about 0.5 A.U. at opposition. The wavelengths of observation were 3.5 cm and 12.6 cm at the Goldstone and Arecibo facilities, respectively. Observational conditions and site locations are summarized in Table 1.

The use of radar in site selection for Viking 1 was based on properties of radiowave scatter in the immediate vicinity of the sub-Earth point on Mars. Near that point, radiowave scatter is dominated by the multitude of reflections from those portions of the surface that are properly oriented to produce a mirrorlike, or near-specular, redirection of the incident energy back toward Earth. This component of the scatter is dubbed quasi-specular. For surfaces that are generally free of sharp discontinuities and are of homogeneous material and statistics, it can be shown that quasi-specular scatter is controlled by the combination of the surface slope distribution and the electromagnetic properties of the material (*3*). Under these conditions the effects of surface material and roughness are readily separated with the use of standard radar astronomy techniques (*4*). Methods used here, based on backscatter at normal incidence, should not be confused with earlier radar studies of lunar landing sites that were based on backscatter observed at oblique angles of incidence, especially the depolarized part of diffuse scatter (*5*).

Both observatories transmitted unmodulated signals. Echoes of these signals were broadened in frequency by the Doppler effect and the differing relative velocities of various scattering areas with respect to the radar. The broadening associated with quasi-specular scatter is quantitatively related to the distribution of surface slopes. A gauge of surface roughness was obtained from measurements of the one-half power bandwidth of the echo signals. The results were expressed in terms of an r.m.s. landing slope β_0. Comparative values of β_0 for lunar units are given in Table 2. The methods employed have been previously tested by comparing radar results from the moon with detailed analyses of the lunar surface at the same locations based on orbital photogrammetry (*6*).

Reflectivity corresponds to the Fresnel reflection coefficient of the mean surface material, or $\rho_0 = [(\sqrt{\epsilon} - 1)/(\sqrt{\epsilon} + 1)]^2$, where ϵ is the dielectric constant. The relationship between density of the surface and ϵ has been established from laboratory experiments and theory (*7*). The lateral scale of relevant slopes is of the order of from 1 to 10 m based on theoretical considerations and on empirical results from the moon (*8*); estimates of ρ_0 apply to the top few centimeters of the surface.

Values of β_0 depend primarily on the shape of the echo spectrum, and are generally free of systematic error. Estimates quoted below are typically accurate to about 10 percent. Estimates of ρ_0 depend on a number of multiplicative parameters which are obtained by calibration of the radar. In addition, ρ_0 is sensitive to variations in the radar, such as antenna point-