Reports

Viking Bistatic Radar Observations of the Hellas Basin on Mars: Preliminary Results

Abstract. *Preliminary reduction of Viking bistatic radar data gives root-mean-square surface slopes in the Hellas basin on Mars of about 4° on horizontal scales averaged over 10 centimeters to 100 meters. This roughness decreases slightly with position along the ground track, south to north. The dielectric constant in this area appears to be approximately 3.1, greater than the martian average. These values are characteristic of lunar maria and are similar to those found near the Viking lander site in Chryse with the use of Earth-based radar.*

Radio transmissions from the Viking orbiters were used to probe the electromagnetic properties and surface roughness of Mars from November 1977 through March 1978. Right circularly polarized signals 13 cm in wavelength from the spacecraft were directed toward the martian surface by the high-gain antenna normally used for communications with Earth. The reflected signals were received with one of the antennas (64 m in diameter) of the NASA Deep Space Network stations at Canberra, Australia, or Goldstone, California. Twenty-nine observations were carried out; we discuss here the preliminary analysis of 32 minutes of data during which the reflection region was within the Hellas basin.

The experimental geometry and a sample power spectrum of the received signal are shown in Fig. 1. For the observations described here, the spacecraft high-gain antenna was continuously aimed toward the point on the mean spheroidal surface, the specular point, that would result in a mirrorlike reflection toward Earth. This point was the approximate center of the region that accounted for the strongest part of the received echo. The geometry varied with the motion of the spacecraft in its orbit so that the specular point traced a path across the surface.

The reflection from a rough planetary surface may be visualized as a multiplicity of rays individually reflected from points in a small region about the mean specular point. The actual reflecting points may be thought of as individual surface elements tilted in such a way that the ray from each is directed to Earth. The frequencies of these rays are differentially shifted a small amount by the slight differences in the rate of change of length of the individual paths from the spacecraft to the surface and back to Earth. The broadened signal near the tip of the specular ray (Fig. 1) is typical of the echo that resulted. The flat portion of the spectrum is the receiver noise level. In general, an increase in surface roughness increases the width of the echo spectrum. The detailed characteristics of the echo have been related to models of the surface roughness (*1*, *2*). In particular, the width of the echo spectrum for a homogeneous and isotropic surface described by Gaussian statistics is proportional to the root-mean-square (r.m.s.) slope.

The total power in the echo depends on the reflectivity of the surface, a function of the dielectric constant, and the geometry; it is independent of roughness to the second order (*3*). Since the width of the echo spectrum does not depend on surface reflectivity if the material is homogeneous, the roughness and dielectric constant may be derived independently from data such as those obtained during these observations.

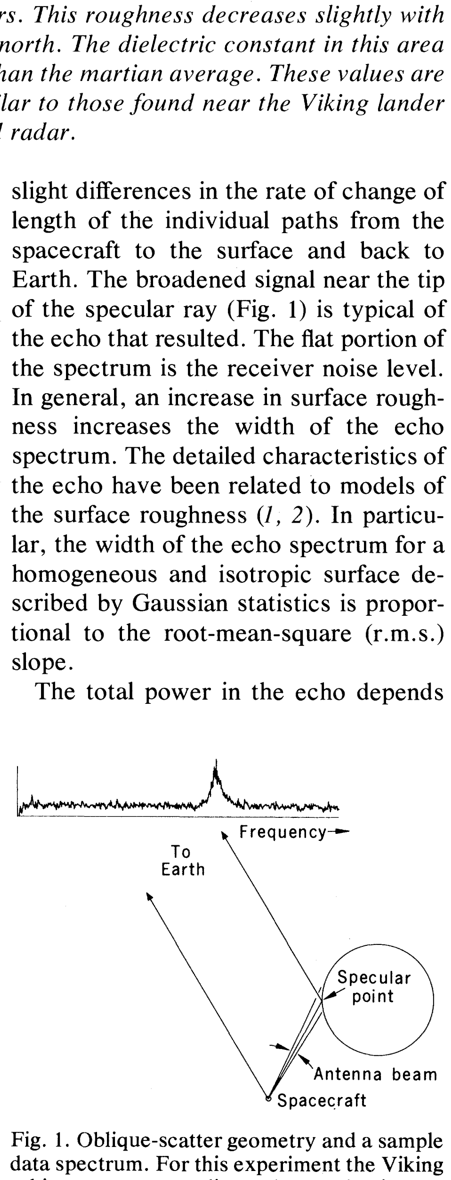

Fig. 1. Oblique-scatter geometry and a sample data spectrum. For this experiment the Viking orbiter antenna was directed toward points on Mars where the angles of incidence and reflection for the mean surface would be equal. The track in this case crossed the Hellas basin. The echo spectrum received on Earth has approximately Gaussian shape and is superposed on noise. The total spectrum plotted here is linear in power (vertical axis) versus a frequency of 0 to 5000 Hz (horizontal axis). The data shown were averaged over 10 seconds.

For this analysis we took advantage of the property of dielectrics that the specularly reflected signal would be linearly polarized in the plane perpendicular to the plane of incidence when the angle of incidence was at the Brewster (or polarizing) angle. The reflected wave would then display equal power in oppositely rotating circular components. By determining the incidence angle for which we obtained equal power in right and left circular polarizations, we identified the Brewster angle θ_B and obtained the dielectric constant

$$\epsilon = \tan^2 \theta_B$$

A similar approach was used by Tyler (*4*) to find $\epsilon = 3.0$ in Oceanus Procellarum on the moon. By modeling the surface as a packed powder, we may use the Rayleigh mixing formula and relate the dielectric constant to the bulk density of the material responsible for the reflection, the upper few centimeters of surface (*5*).

The ground track for this experiment starts near 296°W, 47°S, and runs approximately northwest to 300°W, 40°S. At the beginning of this track, the spacecraft was about 9000 km from the specular point; at the end it was about 5000 km. The angle of incidence at the specular point decreased from about 63° to about 57° during this period.

The transmitted signal power was 12 W at a carrier frequency near 2297 MHz. Additional power was radiated as telemetry modulation, but this power was sufficiently displaced in frequency from the carrier to be of no concern here. The transmitting antenna was a parabolic dish with a gain of 28.4 dB and a beam of 6° between the half-power points. In the main antenna beam, power transmitted in right circular polarization exceeded that in left circular polarization by more than 20 dB. Power radiated by way of side lobes of the antenna was negligible for the purposes of this experiment except that occasionally a weak signal directly from the spacecraft appears in the data. This direct signal is usually well separated from the echo by differential Doppler effects.

Values of the r.m.s. surface roughness (Fig. 2a) are taken from the left circularly

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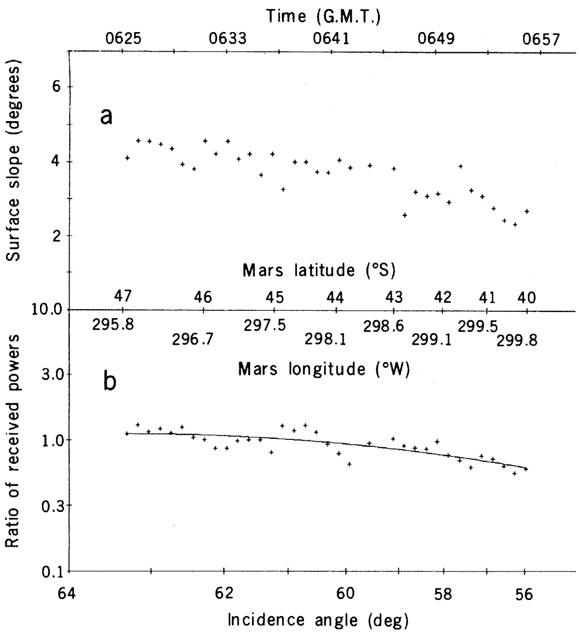

Fig. 2. Root-mean-square surface slope and the ratio of circular polarizations in Hellas. Each point plotted is the average of ten independent estimates. (a) The surface roughness is expressed as tilt with respect to the mean surface. (b) The points are the measured ratios of right to left circular polarization. The curve is the least-square-error quadratic fit. The curve is unity at a Brewster angle $\theta_B = 60.6°$.

polarized receiver channel. The numbers represent the standard deviations of the surface slope expressed in degrees. The right circular channel (not shown here) gives similar, but slightly higher, values. The reason for this difference is not known. In both cases we used a rather simple algorithm to automatically determine these values by comparing the half-power bandwidth of the echo with Fjeldbo's (*1*) prediction for a model surface. We have verified the methods, using Apollo data from the moon (*6*).

Noise in the data causes an underestimation of the surface roughness; this error should be less than about 25 percent. Uneven illumination of the scattering area resulting from the tapered pattern of the high-gain antenna beam may also lead to underestimation of the surface roughness. Our calculations indicate that, under the geometrical conditions of this particular ground track and for the roughness values obtained, this source of error was not important. Uncorrected echo drift in frequency during the 10-second averaging interval used in this analysis causes an artificial broadening of the signal, which results in a 5 to 10 percent overestimation of roughness.

The typically 4° values of the r.m.s. slope (Fig. 2a) are somewhat larger than the average for Mars obtained in earlier studies in which Earth-based systems were used (*7, 8*). The region is certainly rougher than the high plateau south of Valles Marineris (1° r.m.s. slope) and smoother than the plain west of Arsia Mons (8° to 15°) (*9, 10*); it has twice the roughness of Syrtis Major (*11*), a basin in the equatorial region. The area might be comparable to the final Viking lander 1 site, which also appears to have an r.m.s. slope of about 4° at the same (10 cm to 100 m) horizontal scale (*11, 12*).

There appears to be a trend toward smoother surfaces as the reflecting region moves from south to north across Hellas. At the northern end of the track, the roughness has dropped to less than 3°. We know from earlier work in the equatorial region that rapid spatial variations in small-scale texture are common, even in the absence of larger-scale, visible features (*8*).

Figure 2b shows the ratio of right to left circularly polarized received powers, plotted on a logarithmic scale. At the Brewster angle the ratio should be unity. The best-fit quadratic to the data points suggests $\theta_B = 60.6°$, or $\epsilon = 3.1$. Because of the oscillations about the fitted curve, caution must be used in setting any specific figure. There may be variation in the surface as well as uncertainty in the estimation procedure.

A value for ϵ of 3.1 corresponds to a surface density of 1.6 to 1.7 g/cm^3 in the upper few centimeters of regolith, if we assume that the geological material is a packed powder (*5*). This value is significantly larger than that found in equatorial regions in which Earth-based systems were used; Downs *et al.* (*9*) obtained a value of $\epsilon = 2.8$ from their measurements. The lunar values of Tyler and Howard (*4, 13*), $\epsilon = 3.0$ to 3.1, obtained by oblique scatter from Oceanus Procellarum and Mare Serenitatis, were larger than the estimates for Sinus Medii and the Central Highlands ($\epsilon \sim 2.8$) derived from both Earth-based (*14*) and spacecraft studies (*13*).

Our limited data sample indicates that the central portion of Hellas is similar in roughness and average surface density to the lunar maria. Although texture on the order of a wavelength and lateral variations in ϵ may be important to the detailed scattering in Hellas (for example, polarization properties of the surface), we predict that a person would encounter about the same degree of ease or difficulty with the topography in walking across either surface, Hellas or the lunar maria.

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6. We find the average peak amplitude of the five frequency bins centered on the absolute peak. From the absolute peak we move outward on both sides to the first bins where the amplitude is 50 percent of the average peak. We take the spread between these two points to be the half-power width. The roughness is then found with the use of equation 6 of G. L. Tyler and R. A. Simpson [*Radio Sci.* **5**, 263 (1978)], except that we have increased it by a factor of $\sqrt{2}$ to produce the more conventional adirectional r.m.s. surface roughness or landing tilt. For comparison with photogrammetric results, see: H. J. Moore, G. L. Tyler, J. M. Boyce, R. W. Shorthill, T. W. Thompson, A. S. Walker, D. E. Wilhelms, S. S. C. Wu, S. H. Zisk, *U.S. Geol. Surv. Interagency Rep. Astrogeol. 75* (1975), pp. 75–284; H. J. Moore, G. L. Tyler, J. M. Boyce, R. W. Shorthill, T. W. Thompson, D. E. Wilhelms, S. S. C. Wu, S. H. Zisk, *U.S. Geol. Surv. Interagency Rep. Astrogeol. 80* (1976), pp. 76–298.
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