ASSESSMENT OF MARS PATHFINDER LANDING SITE PREDICTIONS. M. P. Golombek[1], A. F. C. Haldemann[1], H. J. Moore[2], T. J. Parker [1], and J. T. Schofield[1], [1]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109, [2]U. S. Geological Survey, Astrogeology Team, Menlo Park, CA 94025.

Selection of the Mars Pathfinder landing site took place over a two and a half year period in which engineering constraints were identified, surface environments and safety considerations were developed (for the robust lander), and the potential science return at different sites was considered. Sites (100 by 200 km target ellipses) were considered safe if they were below 0 km elevation, were free of obvious hazards (high-relief surface features) in high-resolution (<50 m/pixel) Viking orbiter images and had acceptable reflectivity and roughness at radar wavelengths, high thermal inertia, moderate rock abundance, low red to violet ratio, and low albedo [1, 2]. The Ares Vallis landing site was selected because it appeared acceptably safe and offered the prospect of analyzing a variety of rock types expected to be deposited by catastrophic floods, which enable addressing first-order scientific questions such as differentiation of the crust, the development of weathering products, and the nature of the early martian environment and its subsequent evolution [2]. In selecting the Ares Vallis site using the remotely sensed data and the geologic setting, a number of predictions of the surface characteristics of the site were made, which are tested next [3].

The average elevation of the center of the site was predicted to be at about the same elevation as Viking Lander 1 relative to the 6.1 mbar geoid, based on delay-Doppler radar measurements [4] and on tracking results [5]. The Doppler tracking and two-way ranging estimate for the elevation of the spacecraft is 3389.73±0.05 km relative to the center of mass of the planet [6]. The elevation of the lander with respect to the geoid is -1.695, only 45 m lower than Viking Lander 1, and within 100 m of that expected, which is within the uncertainties of the measurements (results for the Mars 50th order and degree geoid [7] indicates Pathfinder is 17 m lower than Viking Lander 1).

The atmospheric conditions used in the Pathfinder entry, descent and landing design were based on a combination of Viking data, Earth-based observations, and general circulation models [8]. As the Viking 1 and Pathfinder landing sites are at similar latitudes and altitudes, Viking 1 surface temperatures, pressures and winds at the Pathfinder landing season and local solar time were assumed. Considerable margin was provided to accommodate uncertainties in vertical temperature structure and vertical wind shear in the lower 10 km of the atmosphere was scaled from terrestrial wind shear data sets. After landing, surface pressures and winds (5-10 m/sec) were found to be very similar to expectations (see low level winds in [2]), although temperatures were approximately 10 K warmer [9]. The temperature profile below 50 km was also roughly 20 K warmer. As a result, predicted densities were 5% high near the surface and up to 40% low at 50 km, but well within the entry, descent and landing design margins [8].

The gently undulating surface around the lander is consistent with the reasonably hazard-free surface predicted with high-resolution (38 m/pixel) images of the landing site [2]. Only 1% of the surface was measured to be covered by craters in Viking orbiter images [2] and only 3 small craters are visible from the lander (1.5 km, 0.15 km and 0.14 km diameters). Small hills and mesas measured in orbiter images cover about 1% of the landing ellipse surface and photoclinometry measurements indicated generally low slopes (average slopes of 10°, maximum slopes of 25° [2]). Slopes of north and south Twin Peaks measured in IMP images are consistent with these estimates (14°-27°). Larger hills such as Far, Southeast, and North Knobs have steeper slopes (>30°), consistent with their steeper slopes in high-resolution Viking topographic maps. Preliminary estimates of root-mean-square slopes based on topographic maps from lander images are about 4° [3] over length scales similar to 3.5 cm delay-Doppler radar slopes of about 5° [4].

A rocky surface was expected from Viking Infra-Red Thermal Mapper (IRTM) observations and comparisons with the Viking landing sites [10, 11, 12]. The cumulative fraction of area covered by rocks with diameters greater than 3 cm within an annulus 3-6 m around the lander is near 16.1% [3]. Expectations were about 20% (18% for the pixel containing the landing site) from IRTM observations [10]. The IRTM estimate postulated an effective thermal inertia of 30 (10^{-3} cgs units) for the rock population which corresponds to a rock about 0.15 m across [10, 11]; below we obtain a modestly different effective thermal inertia for the rock population. Model size-frequency rock distribution estimates for the Ares Vallis site derived from those measured at the Viking landing sites, Earth analog sites, and from IRTM estimates suggested that about 1-3% of the area would be covered by potentially hazardous rocks that are greater than 1 m in diameter or 0.5 m high [2, 13], compared with 1.5% measured around the lander.

The validity of interpretations of radar echoes prior to landing are supported by a simple radar echo model [14], an estimate of the reflectivity of the soil, and the fraction of area covered by rocks. In the calculations, the soil produces the quasi-specular echo and the rocks, which generally have knobby surfaces, produce the diffuse echo. The model [14] relates the total cross-section of the polarized echo (σ_{oc}) with the quasi-specular component (σ^{Q}_{oc}) and the diffuse component (σ^{D}_{oc}): $\sigma_{OC}=\sigma^{Q}_{oc}+\sigma^{D}_{oc}$. The quasi-specular component is related to the normal reflectivity (ρ_o), the root-mean-square slope in radians (Θ_r), a number near unity (n), and the area (X) producing the quasi-specular echo. The diffuse component is related to the reflectivity of the wavelength scatters (ρ_r), the directivity (g), and the fraction of area of scatterers producing the diffuse echo: $\sigma_{oc} = \rho_o(1 + n\ \Theta_r^2)X + \rho_r\ g(1-X)$, where ρ_o=0.06, Θ_r=4.8°, X=0.839, ρ_r =0.23, and g=2. For the soil, the reflectivity is estimated to be near 0.060 in a two-step process. First, the soil is assumed to be similar to lunar soil so that its bulk density can be taken as ~1.55 g/cm^3 because its friction angle is 36-37° [2, 15, 16]. Second, the reflectivity is estimated from a relation between bulk density and normal reflectivity [16]. In the model, the quasi-specular cross-section is reduced to 0.051 by the fraction of area covered by the reflector (0.839) and enhanced (1.007) by the root-mean-square slope (taken as 4.8°) term. This is comparable to the reflectivities of 0.06±0.02 reported from the 3.5-cm delay-Doppler observations (for small root-mean-square-slopes, reflectivities and quasi-specular cross-sections are nearly equal), which are modestly larger than the 0.045 reported for the continuous-wave observations [4]. For the diffuse echo, rocks cover 16.1% of the surface and are assumed to have a reflectivity and directivity appropriate for rocks (0.23 and 2 [14]). With these values, the model yields a polarized diffuse echo of 0.07 - a value close to the 0.055 reported for 3.5-cm wavelength observations [4]. At 12.5-cm wavelength, similar rock populations at Ares and the Viking 1 site are expected because the diffuse echoes are comparable [17], but the large quasi-specular reflectivities (~0.12-0.13) suggests bulk densities greater than 2.2 g/cm^3. One possible explanation is that bulk densities of soils (perhaps like Scooby Doo) at depth are larger than those at the surface.

We estimate an effective thermal inertia near 40 (10^{-3} cgs units) for the entire rock population (compared with the IRTM estimate of 30) by summing the products of the thermal inertias and areas for each rock and dividing by the total area covered by the rocks. In the estimate [18], rocks greater than 0.26 m have inertias near 50 (10^{-3} cgs units) and smaller ones vary as the 0.75 power of their diameter; 0.03 m rocks have inertias near 10. Using a bulk thermal inertia of 10.4 [19] for the landing site and a graphical representation of Kieffer’s model [20], we obtain a fine-component inertia near 8.4 which agrees with the fine-component inertia of 8.7 (in 10^{-3} cgs units) estimated from thermal observations from orbit by the IRTM [21].

Color and albedo data suggested surfaces of materials at Ares Vallis would be relatively dust free or unweathered prior to landing [2] compared with the materials at the Viking landing sites. This suggestion is supported by the abundance of relatively dark-gray rocks at Ares and their relative rarity at the Viking landing sites, where rocks are commonly coated with bright red dust [22].

Finally, the 40 km long Ephrata Fan of the Channeled Scabland in Washington state, which was deposited where channelized water flowing down the Grand Coulee filled the Quincy Basin, was suggested as an analog for the landing site [23] because the overall geology and geomorphology of the landing site, as interpreted from orbital images prior to landing, are compatible with such a depositional plain [2]. The geology and geomorphology of the landing site [3] is similar to such a depositional plain and the abundance and size of pebbles, cobbles and boulders are consistent with the expected general decrease in clast size from the mouth of the channel [2, 24].

The prediction of the important characteristics of the site for safe landing and roving indicates that remote sensing data at scales of kilometers to tens of kilometers can be used to infer surface properties at a scale of meters [2, 3]. The prediction that the site would be a plain deposited by a catastrophic flood is consistent with that found at the surface and implies that some geologic processes observed in orbiter images can be used to infer surface characteristics where those processes dominate over other processes affecting the martian surface layer [11]. Analyses of rock chemistry and close up rover images suggest that a variety of rock types are present, consistent with it being a "grab bag" of materials deposited by the flood [3].

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