THE MARS PATHFINDER MISSION AND SCIENCE RESULTS. M. P. Golombek. Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109.

Mars Pathfinder, one of the first low-cost, quick Discovery class missions, successfully landed on the surface of Mars on July 4, 1997, deployed and navigated a small rover, and collected data from 3 science instruments and 10 technology experiments. The mission operated on Mars for 3 months and returned 2.6 Gbits of new data, including over 16,000 lander and 550 rover images, 16 chemical analyses of rocks and soil, and 8.5 million individual temperature, pressure and wind measurements. The rover traversed 100 m clockwise around the lander, exploring about 200 square meters of the surface. The mission captured the imagination of the public, garnered front page headlines during the first week. A total of about 566 million internet "hits" were registered during the first month of the mission, with 47 million "hits" on July 8th alone, making the Pathfinder landing by far the largest internet event in history.

Pathfinder was the first mission to use a rover, carrying a chemical analysis instrument, to characterize the rocks and soils in a landing area over hundreds of square meters on Mars, which provides a calibration point or "ground truth" for orbital remote sensing observations [1, 2]. The combination of spectral imaging of the landing area by the lander camera, chemical analyses aboard the rover, and close-up imaging of colors, textures and fabrics with the rover cameras offered the potential of identifying rocks (petrology and mineralogy). With this payload, a landing site in Ares Vallis 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]. The 3 instruments and rover allowed seven areas of scientific investigation: the geology and geomorphology of the surface, mineralogy and geochemistry of rocks and soils, physical properties of surface materials, magnetic properties of airborne dust, atmospheric science including aerosols, and rotational and orbital dynamics of Mars.

The spacecraft was launched on December 4, 1996 and had a 7 month cruise to Mars, with four trajectory correction maneuvers. The vehicle entered the atmosphere directly following cruise stage separation. Parachute deployment, heatshield and lander separation, radar ground acquisition, airbag inflation and rocket ignition all occurred before landing at 2:58 AM true local solar time (9:56:55 AM PDT). The lander bounced at least 15 times up to 12 m high without airbag rupture, demonstrating the robustness of this landing system. Soils near the lander that had been disturbed appear to be a darker red-brown than the surrounding undisturbed soils and appear to record the final roll and bounces from the east or east-southeast of the airbag-enclosed lander. The radio signal from the low-gain antenna was received at 11:34 AM PDT indicating successful landing.

Five prominent horizon features, including 3 knobs, one large crater on the horizon and two small craters have been identified in lander images and in the high-resolution Viking orbiter images, which allows the lander to be located with respect to other surface features [3]. Based on azimuths to the features, the location of the lander in the Viking images can be determined to within a few pixels (about 100 m). Within the USGS cartographic network the lander is located at 19.17°N, 33.21°W, but a revised cartographic network [4] for the local area and the two-way ranging and Doppler tracking [5] results in inertial space suggest that the USGS network is displaced about 19 km to the north and 7 km to the west.

Many characteristics of the landing site are consistent with its being shaped and deposited by the Ares and Tiu catastrophic floods [6]. The rocky surface is consistent with its being a depositional plain (16% of the area is covered by rocks) with semi-rounded pebbles, cobbles and boulders that appear similar to depositional plains in terrestrial catastrophic floods. The Twin Peaks appear to be streamlined islands in lander images, which is consistent with interpretations of Viking orbiter images of the region that suggest the lander is on the flank of a broad, gentle ridge trending northeast from Twin Peaks [3]. This ridge, which is the rise to the north of the lander, is aligned in the downstream direction from the Ares and Tiu Valles floods, and may be a debris tail deposited in the wake of the Twin Peaks. Rocks in the Rock Garden may be imbricated or inclined blocks generally tilted in the direction of flow. Channels visible throughout the scene may be a result of late stage drainage. Large rocks (>0.5 m) appear tabular, semi-rounded, and many appear perched, consistent with deposition by a flood. Smaller (<0.3 m) angular darker rocks and blocks may be ejecta from a nearby crater [6]. Evidence for eolian activity at the site includes wind tails behind rocks and wind streaks of what appears to be very fine grained bright red drift material, similar in color to dust in the atmosphere. Dirt covering the lower 5-7 cm of several rocks suggest that they have been exhumed [6]. Some rocks appear to be fluted and grooved by saltating sand size particles in the wind and light colored sand dunes have been imaged in the trough behind the Rock Garden by the rover.

In general, rocks are dark gray with discontinuous coatings of bright red dust and/or weathered surfaces [6]. Undisturbed dark soil, which appears dark (black) in surface images, and dark red soil, which appears in areas disrupted by the rover and airbags, have colors between the bright red and dark gray. A very bright red material (e.g., Scooby Doo) may be an indurated soil, because its composition is similar to soils elsewhere at the site [7].

Soil compositions are generally similar to those measured at the Viking sites, which are on opposite hemispheres. Thus this soil may be a globally deposited unit on Mars [7]. The similarity in compositions among the soils implies that the differences in color may be due to either slight differences in iron mineralogy or differences in particle size and shape.

The analyzed rocks are consistent with basaltic to andesitic parent materials on Mars [7]. The high silica content of some of the rocks appears to require crustal differentiation of mantle derived parent materials. These rocks have compositions that are distinct from those of the martian meteorites. Analyses of lower silica rocks appear rich in sulfur implying that they are covered with dust or weathered. Rover images show some rocks appear vesiculated and may be volcanic. Soils are chemically distinct from the rocks measured at the landing site [7].

Airborne magnetic dust has been progressively deposited with time on most of the magnetic targets on the lander [8]. The dust is bright red and has a magnetization consistent with composite particles with a small amount of maghemite as stain or cement. Interpretation of these results suggests that the iron was dissolved out of crustal materials in water, suggesting an active hydrologic cycle on Mars, and the maghemite is a freeze-dried precipitate.

Observations of wheel tracks and soil mechanics experiments suggests that compressible, drift, cloddy and indurated surface materials are present [9]. Bright red drift material and others may be very fine grained dust; most are composed of poorly sorted dust, sand-sized particles, lumps of soil, and small rocks. Angles of repose and internal friction are like those on Earth and imply bulk densities of surface materials between 1.2 and 2 g/cm^3. Rover images show a large number of loose spherically rounded pebbles and cobbles on the surface. Some rocks show reflective hemispheric pockets or indentations and rounded pebbles, implying that the rock is a conglomerate [9]. Conglomerates require running water to smooth and round the clasts and to deposit the materials and argues for a warmer and wetter past in which liquid water was stable and the atmosphere was thicker.

The atmospheric opacity has been about 0.5 since landing on Mars [6] in late northern summer (Ls of 143°). Slightly higher opacity at night and early in the morning may be due to clouds, which have been imaged, and fog. The sky has been a pale-pink color and particle size (roughly a micron) and shape and water vapor (about 10 precipitable microns) in the atmosphere are all consistent with measurements made by Viking [10]. The upper atmosphere (above 60 km altitude) was relatively cold, although this may be consistent with seasonal variations and entry at 3 AM local solar time (compared with the warmer upper atmosphere measured by Viking at 4 PM local solar time [11, 12]). The multiple peaks in the landed pressure measurements and the entry and descent data are indicative of dust uniformly mixed in a warm lower atmosphere, again similar to that measured by Viking [13].

The meteorology measurements show repeatable diurnal and higher order pressure and temperature fluctuations [12]. The barometric minimum was reached at the site on sol 20 indicating the maximum extent of the winter south polar cap. Temperatures fluctuated abruptly with time and between 0.25 and 1 m height in the morning. These observations suggest that cold morning air was warmed by the surface and convected upward in small eddies. Afternoon temperatures, after the atmosphere has been warmed do not show these variations. Winds have been light (<10 m/s) and variable, peaking at night and during daytime. Dust devils have been detected repeatably in the early afternoon [12].

Daily Doppler tracking and less frequent two-way ranging during communication sessions between the spacecraft and Deep Space Network antennas have resulted in a solution for the location of the lander in inertial space and the direction of the Mars rotation axis [5]. Combined with earlier results from the Viking landers, this gives a factor of three improvement in the Mars precession constant. The estimated precession rate is consistent with the hypothesis that the non-hydrostatic component of the polar moment of inertia (0.3653±0.0056) is due to the Tharsis bulge [5]. The estimated precession constant rules out warm interior models with mantle compositions similar to Earth and cold, highly iron enriched models. If the (iron-enriched) Shergottite meteorites are typical of the mantle composition, then the mantle must be warmer than Earth's (for the same pressure level) and the core radius must be larger than ~1300 km (but no larger than ~2000 km for other mantle compositions).

Taken together, the rounded pebbles, cobbles and the possible conglomerate, the abundant sand- and dust-sized particles and models for their origin, and the high silica rocks, all appear consistent with a water rich planet that may be more Earth like than previously appreciated, with a warmer and wetter past in which liquid water was stable and the atmosphere was thicker [3].

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