Mars Pathfinder, the first low-cost, quick Discovery class mission to be completed, 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 2.3 Gbits of new data, including over 16,500 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, and 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 at the time.

Pathfinder was the first mission to deploy a rover on Mars. It carried a chemical analysis instrument, to characterize the rocks and soils in a landing area over hundreds of square meters on Mars, which provided 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 enabled 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. Scientists were assembled into 7 Science Operations Groups that were responsible for requesting measurements by the 3 instruments, rover and engineering subsystems for carrying out their scientific investigations and for analyzing the data and reporting on their findings.

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. Reconstruction of the final landing sequence indicates that the parachute/backshell/lander was tilted due to a northwest directed wind and wind shear, which resulted in the lander bouncing about 1 km to the northwest and initially downhill about 20 m from where the solid rockets fired. Two anomalously bright spots located in the lander scene are likely the heatshield, which continued in a ballistic trajectory about 2 km downrange (west southwest), and the backshell/parachute, which stayed nearer to where the rockets fired. Unconnected disturbed soil patches in the scene indicate that the final few bounces of the lander were from the east-southeast and were followed by a gentle roll to the west before coming to rest on the base petal. The location of the lander away from where the solid rockets fired and considerations of the exhaust products used to inflate the airbags and their fate, indicate that the Pathfinder landing system is one of the cleanest designed leaving the local area essentially contaminant free. The radio signal from the low-gain antenna was received at 11:34 AM PDT indicating successful landing.

Because the lander and rover were solar powered, most real time operations occurred during the Martian day, which shifted 37 min a day relative to time on the Earth, and involved 24 hr staffing during the nominal mission. Scientists and engineers had 3 hours from the end of the last downlink of a sol to analyze the data that had been returned, assess what had been learned, determine the actual location of the rover, and revise plans for the subsequent sol. The next 12 hours involved creating the specific lander, rover and instrument sequences, fitting them in a workable timeline, testing and validating them on a testbed, and uplinking them to the spacecraft at the start of the next sol.

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 19.13°N, 33.22°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 18 km to the north and 9 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 subrounded 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
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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 Tiaw 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, subrounded, 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 rock chemistry is similar to basalts, basaltic andesites, and andesites on the Earth [7]. 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. The chemistry and normative mineralogy of the dust free rocks are similar to those of common terrestrial anorogenic andesites, such as icelandites, which formed by fractional crystallization of mantle derived parent materials. Rover images show some rocks appear vesiculated and may be volcanic. Rover close-up and lander super resolution images show rocks with a variety of morphologies, textures and fabrics such as pitted, smooth, bumpy, layered and lineated, suggesting that a variety of rock types are present at the site. 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. An 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, cloudy 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/cm³. 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 repeatedly in the early afternoon [12] and have been found in lander images.

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 (0.3662±0.0017) 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). The annual variation in rotation agrees with the expected seasonal mass exchange of carbon dioxide between the ice caps and atmosphere.

Taking all the results together supports an early Mars that may be Earth-like. Some crustal materials on Mars may be similar in silica content to continental crust on Earth. The rounded pebbles, cobbles and the possible conglomerate and the abundant sand- and dust-size particles and models for their origin, support a water rich planet in which the early environment was warmer and wetter and liquid water was in equilibrium, perhaps similar to the early Earth. In contrast, Mars, since the Hesperian (1.5-3.5 Ga), appears to be a very un-Earth like place, with very low erosion rates producing minor changes to the surface at the Pathfinder landing site. [3].