universal time (midpoint) on 7 July 1997 at a phase angle of 43.4°. An air mass correction was applied using a wavelength independent optical depth of 0.5.

42. W. Grundy and U. Fink, in *Asteroids, Comets, Meteors 1991* (Lunar and Planetary Institute, Houston, TX), pp. 215–218 (1992); B. Zellner and E. N. Wells, *Lunar Planet. Sci* **XXV**, 1541 (1994).
43. K. P. Klassen, T. C. Duxbury, J. Veverka, *J. Geophys. Res.* **84**, 8478 (1979).
44. L. M. French, J. Veverka, P. Thomas, *Icarus* **75**, 127 (1988).
45. We thank the Pathfinder project team led by A. Spear and B. Muirhead, J. Wellman, T. Tomey, M. Golombek, J. Crisp, R. Anderson. We also thank R. Reynolds, C. Shinohara, R. Singer, L. Doose, D. Crowe, S. Bell, R. Tanner, J. Weinberg, R. Marcialis, T. Friedman, M. Williams, D. Koschny, R. Kramm, H. Hartwig, J. Martin, D. Barnett, M. Bigler, T. Gallagher, J. Eastman, W. Green, S. LaVoie, E. DeJong, A. Runkle, D. Alexander, J. Lorre, M. McAuley, S. Suzuki, and the magnetics group from Denmark led by J. Knudsen.

17 September 1997; accepted 13 November 1997

# Characterization of the Martian Surface Deposits by the Mars Pathfinder Rover, Sojourner

Rover Team*†

Sojourner, the Mars Pathfinder rover, discovered pebbles on the surface and in rocks that may be sedimentary—not volcanic—in origin. Surface pebbles may have been rounded by Ares flood waters or liberated by weathering of sedimentary rocks called conglomerates. Conglomerates imply that water existed elsewhere and earlier than the Ares flood. Most soil-like deposits are similar to moderately dense soils on Earth. Small amounts of dust are currently settling from the atmosphere.

Sojourner, the Mars Pathfinder rover (*1*), made observations that raise and answer questions about the origins of the rocks and other deposits at the Ares site (*2–4*) and allow comparisons with the two Viking sites (*5*). Because the rover is mobile and close to the ground, its observations, embodied in images, reveal details of the textures of rocks and deposits that are not obtainable with a lander camera. Excavations by the rover brought materials to the surface for examination and allowed estimates of the mechanical properties of the deposits (*6, 7*) (Fig. 1A). The rover also carried the α-proton x-ray spectrometer (*8*) to rocks and soils for chemical analyses.

Ares resembles the two Viking sites (*5*) because it is partly covered by thin drifts atop soil-like deposits admixed with rocks (Plate 1A), but there are other similarities and important differences. Rock concentrations are comparable at the three sites (*3*); at Ares, 16.1% of the surface is covered by rocks wider than 3 cm (Plates 5 and 9). Unlike the Viking sites, well-rounded objects a few centimeters wide are found on the surface (Fig. 1B); these objects pose interesting questions. Are they pebbles (*9*) rounded by Ares flood waters, wave action on an ancient martian beach, or a glacier? Are they drops of solidified impact melts or spatter from lava fountains? Are they nodules from depth within lavas, pyroclastic rocks, or concretions, or are they pebbles from sedimentary rocks that were liberated by weathering? We suggest that they may be pebbles liberated from sedimentary rocks composed of cemented silts, sands, and rounded fragments (*9*); such rocks are called conglomerates. On Earth, cements include hardened clay, iron oxide, silica, and calcium carbonate. In the rover images (Fig. 1C), Shark, Half Dome, and a nearby small rock look like they might be conglomerates. The rounded knobs up to 3 or 4 cm wide on Shark and Half Dome could be pebbles in a cemented matrix of clays, silts, and sands. The small rock has small 0.5- to 1-cm–sized pebbles and similar size "sockets" that could be the former sites of pebbles (Fig. 1D). Rocks are not the same everywhere. Some rocks (Stimpy and, perhaps, Hassock) (Plate 6) may be volcanic because they appear to be hexagonal prisms; prismatic rocks, such as basalts and tuffs, are commonly formed by the cooling of volcanic flows. Squash (Plate 6), which has fingerlike protrusions, may be an autobrecciated or pillow lava. Rocks with vesicular and pitted textures could be a result of volcanic, sedimentary (*1*), or weathering processes (Fig. 1E).

These observations are important for the following reasons (i) knobby rocks may be conglomerates formed from silts, sands, and pebbles deposited from streams or floods or along coasts; cemented by hardened clay or by the precipitation of silica, iron, and sulfur compounds (or by both); or incorporated as conglomerates in waters of the Ares floods and redeposited 1 or 2 billion years ago as part of the Ares fan; (ii) pebbles in conglomerates would suggest that liquid water existed at the surface before the Ares floods; (iii) some rocks may be sedimentary and others volcanic; (iv) the unexpected high silica contents in some rocks (*8*) may be due to sedimentary processes, such as cementation and sorting; (v) sulfur compounds (*8*) could be present in a hardened-clay cement; and (vi) the Ares site appears to be a place where a "grab bag" sample was collected (*2, 3*).

In general, martian soil-like deposits (*6*) (Table 1) are similar to moderately dense soils on Earth, such as clayey silt with embedded sands, granules, and pebbles, and a test material that simulates lunar soil (*10*). Friction angles (Φ) average about 36.6° and are typically between 32° and 41°; angles of repose (Θ) measured with lander camera images (*4*) average 34.2° and are typically between 30° and 38°. Cohesion ($c$) values calculated with the assumption that Φ equals Θ average 0.238 kPa and are typically between 0.120 and 0.356 kPa (Table 1) (*6*). The bulk density of the deposits may be estimated from their Φ with the assumption that they behave like lunar soils (*10*), giving an average bulk density of the deposits near 1520 kg/m$^3$. Deposits are not the same everywhere. In compressible dust, a rover wheel produced ruts with steep walls, marginal slumps, and nearly perfect reflective casts of the spacing between the cleats (Fig. 1F), which are the responses expected for a fine-grained, porous deposit subjected to a load near 1 or 2 kPa. The estimated values of Φ near 26° and $c$ near 0.53 kPa (Table 1) indicate a weak, porous deposit. Casper, a nearby bright exposure, may be a consolidated deposit (Fig. 1F) like Scooby Doo (Plate 7C) that has a chemical composition (*8*) similar to soil-like deposits elsewhere (the rover did not scratch or dig into Scooby Doo, nor could it dig into consolidated or cohesive materials such as adobe or hardpan on Earth). Bright, fine-grained drifts are abundant as thin (less than a few centimeters), discontinuous ridged sheets and wind tails that overlie cloddy deposits (Fig. 1G). For example, concurrent values of shear and normal stresses yield an upper layer of drift (1 cm thick) with Φ = 28.2°

The Rover Team: J. R. Matijevic, J. Crisp, D. B. Bickler, R. S. Banes, B. K. Cooper, H. J. Eisen, J. Gensler, A. Haldemann, F. Hartman, K. A. Jewett, L. H. Matthies, S. L. Laubach, A. H. Mishkin, J. C. Morrison, T. T. Nguyen, A. R. Sirota, H. W. Stone, S. Stride, L. F. Sword, J. A. Tarsala, A. D. Thompson, M. T. Wallace, R. Welch, E. Wellman, B. H. Wilcox, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA. D. Ferguson, P. Jenkins, J. Kolecki, G. A. Landis, D. Wilt, NASA Lewis Research Center, Cleveland, OH 44135, USA.

*Contributions by H. J. Moore, U.S. Geological Survey, Menlo Park, CA 94025, USA, and F. Pavlics, 3337 Campanil Drive, Santa Barbara, CA 93109, USA.
†Correspondence should be addressed to H. J. Moore. E-mail: moore@astmnl.wr.usgs.gov

and a substrate of the cloddy deposit (>3.3 cm thick) with $\Phi = 41.0°$ (Table 1). Cloddy deposits, composed of poorly sorted dusts, clods, and rocks $\leq 1$ cm in size (Fig. 1H), were exhumed from beneath a thin layer of drift near Yogi; cloddy deposits form patches of pebbly surfaces and are widespread (Fig. 1, B and G). Platy fragments disturbed during excavations (such as Pop-Tart in Fig. 1H) and by airbag retraction are probably crusts. Different materials are indicated for Mermaid (Fig. 1A) because the relatively dark, gray coloration of its surface may be an armor of basaltic sand or granules and $\Phi$ in the upper 1.4 cm is smaller (35.1°) (Fig. 1I) than $\Phi$ in the substrate of cloddy material (40.6°) (Table 1). On the other hand, reflective wheel tracks and excavations revealed that the Mermaid deposits are poorly sorted with abundant dust.

Mechanically, most Ares deposits resemble crusty to cloddy material at the Viking 2 site, for which $\Phi = 34.5° \pm 4.7°$ and $c$ =

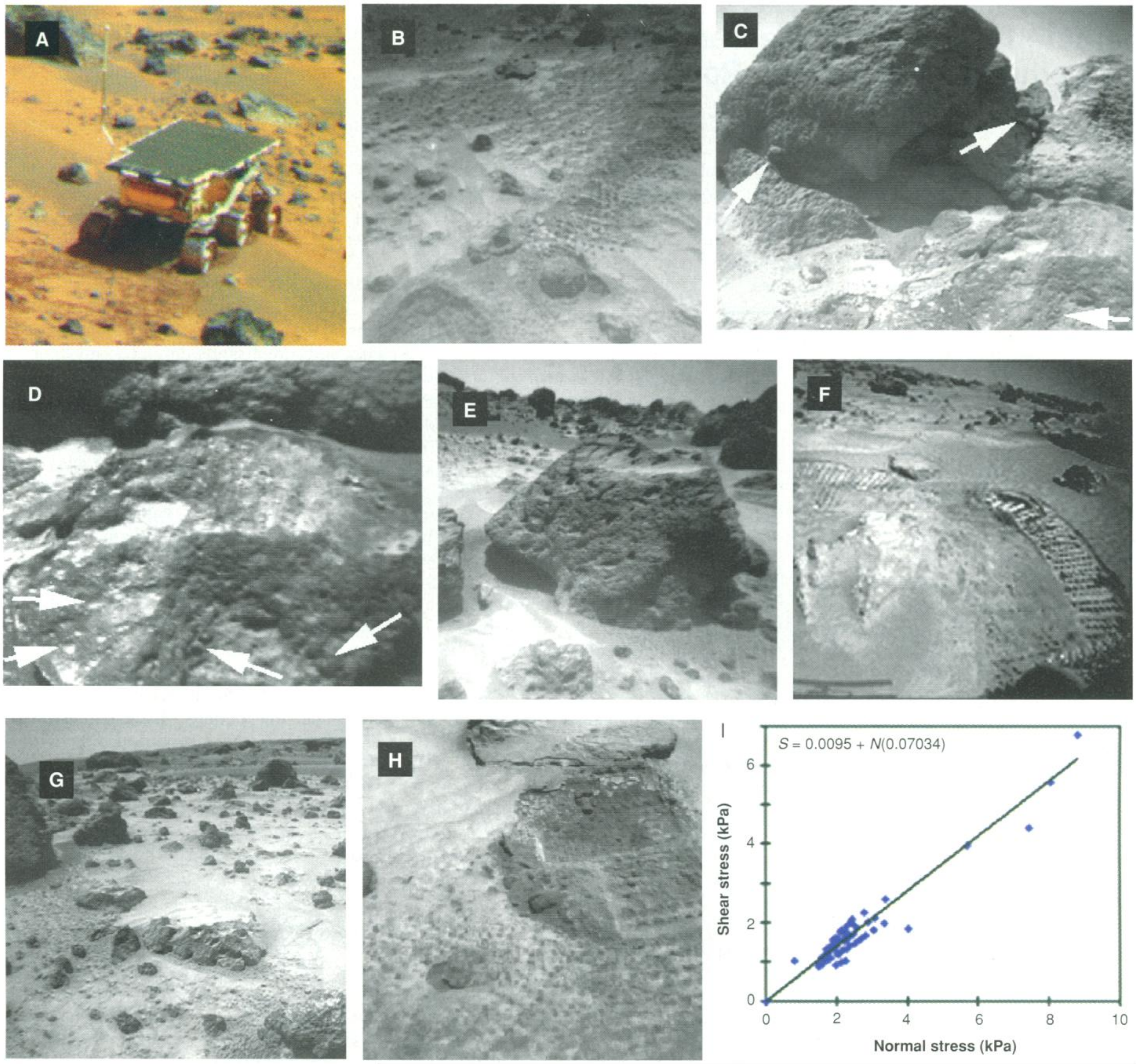


**Fig. 1.** Lander camera image and rover images of the surface of Mars. (**A**) Rover atop the Mermaid "dune" on sol 30. Note the dark material excavated by the rover wheels. The rover is 32 cm tall, 47 cm wide, and 62 cm long. (**B**) Rounded 4-cm-wide pebble at lower center and excavation of cloddy deposit of Cabbage Patch at lower left. Note the bright wind tails of drift material extending from small rocks and the wheel track from upper right to lower left. Part of the scene is 22 cm away where pixels are 0.7 mm wide. (**C**) Knobs (arrows) of Shark (left), Half Dome (upper right), and small rock (right) may be pebbles in a conglomerate. Shark is about 70 cm wide. (**D**) Small rock conglomerate; arrows indicate sockets (left) and pebbles (lower right). (**E**) Soufflé rock (32 cm wide) has a pitted surface. (**F**) Mosaic showing rover tracks (7 cm wide) in compressible soil. The bright area at lower left may be an indurated soil. (**G**) "Pebbly" surface of cloddy deposit near Pooh Bear at left and bright drifts at right center. (**H**) Excavation through veneer of drift. The excavation is 7 cm wide. The platy fragment or piece of crust (upper right) was displaced by the rover wheel. (**I**) Shear and normal stresses determined concurrently for the upper 1.4 cm during the first test in Mermaid. The tan ($\alpha$) is 0.709; a least squares fit yields $\Phi = 35.1°$ and $c = 0.01$ kPa (Table 1).

**Table 1.** Summary of conditions and results of soil mechanics experiments. Some experiments are pending.

| Exp. No.* | Sol† | Wheel‡ | Number of turns§ | $T$ (°C) | Depth (cm) | Tan ($\alpha$)‖ | $\Theta$ (degrees) | $c$ if $\Phi = \Theta$ (kPa) | $\Phi$¶ (degrees) | $c$¶ (kPa) | Material type | $X$# (m) | $Y$# (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | LF | −0.25 | | 0.4 | 0.850 | 38.3 | 0.21 | 37.0 | set to 0 | Cloddy | 1.5 | −1.5 |
| 2 | 4 | RR | +1.0 | 3.1 | 1.6 | 0.804 | 38.3 | 0.09 | 34.4 | 0.31 | Cloddy | 2.8 | −2.5 |
| | | RF | +1.0 | 1.8 | 0.2 | | | | | | Cloddy | 2.8 | −2.5 |
| 3 | 13 | RR | +1.0 | −2.4 | 1.3 | 0.866 | 38.3 | 0.34 | 41.5 | −0.04 | Cloddy | 3.3 | −1.3 |
| | | RF | +1.0 | −2.4 | 0.2 | | | | | | Cloddy | 3.3 | −1.3 |
| 4 | 13 | RR | +1.0 | 0.3 | 3.8 | 0.753 | 36.8 | 0.15 | 33.3 | set to 0 | Cloddy | 3.3 | 0.0 |
| 5 | 15 | RR | +0.25 | | 0.0 | | | large | | large | Consolidated | 3.1 | 1.2 |
| 6 | 18 | LF | −1.0 | | | | | | | | Cloddy | 2.6 | −1.2 |
| 7 | 18 | LF | −1.0 | | | | | | | | Cloddy | 2.6 | 0.0 |
| 8 | 21 | LR | +1.5 | −6.7 | 6.0 | 0.820 | 38.3 | 0.09 | 42.4 | −0.18 | Cloddy | 3.4 | −0.7 |
| 9 | 23 | RF | −1.0 | −0.2 | 0.8 | 0.495 | 24.0 | 0.36 | 26.4 | 0.53 | Compressible | 3.4 | 1.1 |
| 10 | 27 | RR | +1.5 | −0.9 | 3.7 | 0.806 | 34.0 | 0.27 | 37.1 | 0.08 | Mixed | −2.4 | 4.4 |
| | | RR | +0.48 | | 0–1.2 | 0.773 | 34.0 | 0.30 | 36.9 | 0.04 | Mixed? | | |
| | | RR | +1.02 | | 1.2–3.7 | 0.821 | 34.0 | 0.26 | 41.2 | 0.08 | Cloddy | | |
| 11 | 27 | RR | +1.5 | 3.1 | 4.3 | 0.778 | 34.0 | 0.19 | 36.9 | 0.06 | Mixed | −2.9 | 4.2 |
| | | RR | +0.32 | | 0–1.0 | 0.655 | 34.0 | 0.00 | 28.2 | 0.18 | Drift | | |
| | | RR | +1.19 | | 1.0–4.3 | 0.814 | 34.0 | 0.27 | 41.0 | −0.10 | Cloddy | | |
| 12 | 29 | LR | +1.5 | −35 | 3.2 | 0.662 | 32.4 | 0.40 | 34.7 | 0.23 | Mixed | −5.6 | 2.6 |
| | | LR | +0.46 | | 0–1.4 | 0.709 | 32.4 | 0.18 | 35.1 | 0.01 | "Dune" | | |
| | | LR | +1.04 | | 1.4–3.2 | 0.847 | 32.4 | 0.43 | 40.6 | −0.02 | Cloddy | | |
| | 29 | RF | −1.0 | | | | | | | | Mixed? | −5.6 | 3.0 |
| | 29 | LR | +1.5 | −35 | 1.5 | 0.778 | 32.4 | 0.26 | 38.1 | −0.04 | Mixed? | −6.2 | 2.5 |

*Experiment number (Exp. No.) may include several spins of the same or different wheels in the same material at slightly different locations. †The sol is a Pathfinder martian event day (1 sol = 24.6 hours); sol 1 is the sol of landing. On sols 27 and 29, analyses were made for segments of the data because there is evidence for layering in the depth-time curves and images. ‡Wheel: The first letter indicates left (L) or right (R); the second letter indicates front (F) or rear (R). §The number of full or partial turns; +, forward direction; −, reverse direction. ‖Average apparent friction coefficient calculated for concurrent values of shear or tractive stress and normal stress. ¶Obtained from least squares fits to concurrent values of shear or tractive stress and normal stress; cohesion set to zero ($c$ = 0) in two cases. #Experiments can be located on the maps in the foldout with the $X$ and $Y$ coordinates given.

1.1 ± 0.8 kPa (*11*). Scooby Doo may be analogous to the blocky soil-like material at the Viking 1 site, for which $c$ = 5.5 ± 2.7 kPa (*11*). The deposit near Casper (Fig. 1F) is compressible and resembles drift material at the Viking 1 site (*11*).

Wheel tracks and the wheel abrasion experiment indicate that the deposits contain substantial amounts of dust. Most of the rover tracks have low to nonexistent rims and are reflective (Fig. 1F); such tracks are produced in loose materials with grain sizes of less than about 40 μm, but not in loose sand (*1*). Reflective surfaces can be seen in tracks everywhere, but they are less obvious in "pebbly" areas, which suggests these areas also contain coarser grains and clods up to about a few centimeters wide (Fig. 1B). One rover wheel was covered with thin metal (nickel, platinum, and aluminum) strips electrically isolated from the rover and a photodiode (*1*) to measure abrasion. Instead, the wheel appears to provide an estimate of the particle size of adhering dust. Dust collected on the wheels as soon as the rover traversed on Mars, sometimes producing severely depressed reflectance for the platinum and aluminum metal strips and, at other times, depressed reflectance for the nickel strip. Subsequent wheel revolutions showed that enhanced dust corresponds to wheel strips that were in the shade before the data were taken. That is, the phenomenon is transient, variable, and not metal specific. A possible explanation for the variable adhesion is differential electrostatic charging (*12*). A rolling wheel in conditions of martian atmospheric pressure and composition will charge to several hundred volts. This voltage correlates with the amount of dust adhering to the wheel; large amounts of dust may adhere during traverses on materials with grain sizes less than about 40 μm. Shaded wheel segments charged preferentially because they were unable to discharge by photoelectric effects induced by direct sunlight with its strong ultraviolet component.

The materials adherence experiment monitored dust on the solar array by measuring the optical obscuration. About 2% optical obscuration occurred at landing, possibly as a result of the retraction of the airbag. This dust was removed when the rover petal was lifted, indicating that large particle sizes did not adhere well to the glass. Over the first 30 days, dust accumulated at 0.28% per day. This accumulation seems to be independent of rover motion and reflects dust settling from the atmosphere. If the cross section–weighted average particle size is 2.75 μm, and particle scattering properties are assumed to be those calculated by Pollack *et al.* (*13*), this obscuration corresponds to a mass settling rate of 3 $\mu g/cm^2$ per day, which is similar to the globally averaged sedimentation rate calculated by Pollack *et al.* (*13*).

## REFERENCES AND NOTES


1. The Rover Team, *J. Geophys. Res.* **102**, 3989 (1997). This reference includes the rover characteristics.
2. M. P. Golombek *et al.*, *ibid.*, p. 3967.
3. M. P. Golombek *et al.*, *Science* **278**, 1743 (1997).
4. P. H. Smith *et al.*, *ibid.*, p. 1758.
5. T. A. Mutch *et al.*, *J. Geophys. Res.* **82**, 4452 (1977); A. B. Binder *et al.*, *ibid.*, p. 4439.
6. In our analyses of the mechanical properties of deposits, we used the rover wheel as a shear test device and the Mohr-Coulomb failure criteria (*7*), $S = c + N[\tan(\Phi)]$, where $S$ is shear or tractive stress, $c$ is cohesion, $N$ is normal stress, and tan ($\Phi$) is the coefficient of friction ($\Phi$ is the friction angle). The apparent friction coefficient tan ($\alpha$) is $S/N = (c/N) + \tan(\Phi)$. All of these parameters vary with the projected area $A$. We obtained averages of ratios of concurrent values of $S$ and $N$; we also assumed that $\Phi$ was equal to the angle of repose ($\Theta$) and obtained average values of $c$ from concurrent shear and normal stresses (Table 1); the calculations included the concurrent values of $A$. Shear or tractive force was derived from wheel torque and wheel radius; torque is a function of motor current. The relation used is $M = y(I - x)$, where $M$ is torque [in inch-pounds (1 inch-pound = 0.113 N·m)], $I$ is motor current (in milliamperes), $y$ is a variable (in inch-pounds per milliampere), and $x$ is a no-load current (in milliamperes). Both $y$ and $x$ vary with temperature $T$ (in degrees Celsius): $y = 0.4518 - 0.0013T$ and $x = -(0.0117T^2 + 0.2922T + 6.2084)$. No-load currents vary for each wheel. We solved for the friction angle and cohesion in several ways. In an initial analysis, rough graphical estimates of tan ($\alpha$) for the sol 3 left front and sol 4 right rear wheel data were made, and the two equations were solved to yield $\Phi$ near 38.4° and $c$ near 0.28 kPa. In subsequent analyses, ratios of concurrent shear stresses and normal stresses were obtained (Fig. 1I) and averaged to yield a value of tan ($\alpha$); each ratio was used concurrently with the shear stresses and normal stresses to solve for $c$ with the assumption that $\Phi$ equals the $\Theta$ value estimated from images; the average of these $c$ values is taken as one estimate of $c$. Linear least squares fits to the concurrent shear and normal stresses provide anoth-

er estimate of the friction angle and cohesion (Fig. 1I). Cohesions are negative for 5 of 16 least squares fits to concurrent pairs of shear and normal stresses, but it should also be realized that the cohesions are small and difficult to estimate. The use of the rover wheel as a shear test device was validated in laboratory tests with various soil-like materials.

7. K. Terzaghi, *Theoretical Soil Mechanics* (Wiley, New York, 1948).
8. R. Rieder *et al.*, *Science* **278**, 1771 (1997).
9. Diameters of particles (in millimeters) are as follows: cobbles, 256 to 64; pebbles, 64 to 4; granules, 4 to 2; sand, 2 to 0.062; silt, 0.062 to 0.005; and clay, 0.005 and less. Dust is composed of clay- and silt-sized particles.
10. J. K. Mitchell *et al.*, *Geochim. Cosmochim. Acta* **3**, 3235 (1972).
11. H. J. Moore and B. M. Jakosky, *Icarus* **81**, 164 (1989); R. E. Arvidson *et al.*, *Rev. Geophys.* **27**, 39 (1989); H. J. Moore *et al.*, *J. Geophys. Res.* **87**, 10043 (1982).
12. G. R. Olhoeft, in *Sand and Dust on Mars*, R. Greeley and R. M. Haberle, Ed. (NASA Conference Paper CP-10074, NASA, Greenbelt, MD, 1991), pp. 44–46.
13. J. B. Pollack *et al.*, *J. Geophys. Res.* **84**, 2929 (1979).
14. We thank M. Hirschbein, D. Lavery, A. Runkle, D. Alexander, and S. Arriola. Most of the work was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

5 September 1997; accepted 3 November 1997

# Magnetic Properties Experiments on the Mars Pathfinder Lander: Preliminary Results

S. F. Hviid, M. B. Madsen, H. P. Gunnlaugsson, W. Goetz, J. M. Knudsen, R. B. Hargraves, P. Smith, D. Britt, A. R. Dinesen, C. T. Mogensen, M. Olsen, C. T. Pedersen, L. Vistisen

**Many of the particles currently suspended in the martian atmosphere are magnetic, with an average saturation magnetization of about 4 A·m$^2$/kg (amperes times square meters per kilogram). The particles appear to consist of claylike aggregates stained or cemented with ferric oxide ($Fe_2O_3$); at least some of the stain and cement is probably maghemite ($\gamma$-$Fe_2O_3$). The presence of the $\gamma$ phase would imply that $Fe^{2+}$ ions leached from the bedrock, passing through a state as free $Fe^{2+}$ ions dissolved in liquid water. These particles could be a freeze-dried precipitate from ground water poured out on the surface. An alternative is that the magnetic particles are titanomagnetite occurring in palagonite and inherited directly from a basaltic precursor.**

Both Viking landers had a weak and a strong magnet mounted on the backhoe of their soil samplers (*1*). These magnets were inserted directly into the martian soil. Both magnets became quickly saturated with magnetic material. A strong magnet was also mounted on one of the reference test charts on each lander. This magnet captured magnetic particles suspended in the atmosphere. The results of the Viking experiments were interpreted to indicate that the martian soil contained from 1 to 7 weight % of a magnetic (ferrimagnetic) mineral. Maghemite ($\gamma$-$Fe_2O_3$) was favored as the magnetic phase and was inferred to be present as a component of composite particles of silicate and ferric oxide that constituted the bulk of the martian soil. Alternative explanations remained possible, revolving mainly around the idea that the magnetic particles were discrete grains of titanomagnetite (or titanomaghemite) inherited from a basaltic precursor (*2*). If true, the survival of such grains would suggest that chemical weathering on Mars had been less intense than in the former scenario.

The Pathfinder magnetic properties experiment (*3*) was designed to further elucidate the nature of, and constrain the origin of, the magnetic phase in the fine martian soil. The experiment has three components. A pair of magnet arrays is mounted on the lander, each array consisting of five "bull's-eye" magnets, decreasing in strength from right to left (Fig. 1). The ring magnet has an outer diameter of 18 mm, and the disk magnet has a diameter of 6.5 mm. The tip-plate magnet experiment consists of a single strong, off-centered bull's-eye magnet mounted below a wedged surface, to ensure a varying magnetic field strength and gradient over the surface. The tip-plate magnet is about 7 cm from the eye of the camera and was imaged through a diopter lens to increase resolution. Magnets are also mounted at the foot of each rover ramp. The strength of the ramp magnets is equal to that of the arrays' magnet 3. Should the ramp magnets attract magnetic dust, they could be accessed by the rover later in the mission for $\alpha$-proton x-ray (APX) spectrometer analysis. These various magnets were imaged at intervals by the Imager for Mars Pathfinder (IMP). The only particles to which the Pathfinder magnets would be exposed, and could possibly attract, are the particles suspended in the atmosphere.

Here we discuss only the results of the magnet array experiments. The magnets were constructed so that magnet 5 (the weakest) is able to attract and hold magnetite ($Fe_3O_4$, saturation magnetization $\sigma$ = 90 A·m$^2$/kg) and maghemite ($\gamma$-$Fe_2O_3$, $\sigma$ = 70 A·m$^2$/kg), magnet 3 is able to attract and hold feroxyhyte [$\delta$-FeOOH, $\sigma \approx$ 10 A·m$^2$/kg (*4*)], and magnet 1 is able to attract and hold hematite ($\alpha$-$Fe_2O_3$, $\sigma$ = 0.4 A·m$^2$/kg). In this way, all of the magnets will be able to attract and hold pure maghemite, but for example, magnet 2 will not be able to hold macroscopic hematite. A rough estimate of the ability of the magnets to attract dust, that is, the relative capture cross section of the magnets, can be obtained through the product of the magnetic field $B$ and its gradient $\nabla B$ for each magnet, which gives 36.400, 3.150, 1.029, 0.253, and 0.055 T$^2$ m$^{-1}$ for magnets 1 to 5, respectively. The relative strengths of the magnets are thus 100:9:3:0.7:0.15. For example, if magnet 1 (the strongest) needs 50 sols (1 sol = 1 martian day = 24.6 hours) to saturate, magnet 2 needs about 550 sols to saturate, assuming a constant amount of dust in the martian atmosphere. The capture of magnetic particles is, however, a complicated process, depending on several parameters: for example, the magnetization of the particles as a function of the impressed magnetic field $B$, the wind velocity, the particle size, and the effective coefficient of friction of the surface of the magnet array instrument.

By sol 5, a faint bull's-eye pattern (testifying to adhering particles) could be seen

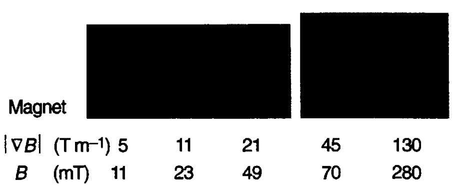


**Fig. 1.** Sketch of a magnet array. A magnet array consists of two magnesium blocks, one containing three magnets and another containing two magnets. The magnets are embedded in the blocks. They are positioned below the surface, and the surfaces are without features when the blocks are pristine. The strengths of the magnets vary from magnet 1 (strongest) to magnet 5 (weakest). The black dots indicate the positions of mounting bolts.

S. F. Hviid, M. B. Madsen, H. P. Gunnlaugsson, W. Goetz, J. M. Knudsen, A. R. Dinesen, C. T. Mogensen, M. Olsen, C. T. Pedersen, L. Vistisen, Oersted Laboratory, Niels Bohr Institute for Astronomy, Physics, and Geophysics, University of Copenhagen, Copenhagen, Denmark.
R. B. Hargraves, Department of Geosciences, Princeton University, Princeton, NJ 08544, USA.
P. Smith and D. Britt, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA.