Density of Mars’ South Polar Layered Deposits

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Both poles of Mars are hidden beneath caps of layered ice. We calculated the density of the south polar layered deposits by combining the gravity field obtained from initial results of radio tracking of the Mars Reconnaissance Orbiter with existing surface topography from the Mars Orbiter Laser Altimeter on the Mars Global Surveyor spacecraft and basalt topography from the Mars Advanced Radar for Subsurface and Ionospheric Sounding on the Mars Express spacecraft. The results indicate a best-fit density of 1220 kilograms per cubic meter, which is consistent with water ice that has ~15% admixed dust. The results demonstrate that the deposits are probably composed of relatively clean water ice and also refine the martian surface-water inventory.

The residual polar-cap component is believed to be composed of water ice with an unknown admixed dust component that is overlain by a thin (1- to 10-m) predominantly CO2 cover (2–4). The CO2 veneer contains “swiss cheese-like” shallow depressions (5) that reveal the underlying water ice at their bases. The more spatially extensive part of the SPLD (Fig. 1) has a low albedo and a dustlike spectral signature, which raises the question of whether the dominant component of the SPLD as a whole is volatile (H2O and/or CO2) or dust. This question is relevant to establishing an accurate inventory of surface volatiles on Mars.

In this study, we used initial high-resolution gravity observations from X-band (8.4 GHz) Doppler tracking of the Mars Reconnaissance Orbiter (MRO) (6) together with the volume obtained by combining surface topography from the Mars Orbiter Laser Altimeter (MOLA) (7) and basalt topography from the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) (8) to calculate the density of the SPLD and constrain their composition. The MRO’s orbital periapsis altitude of ~255 km above the south pole of Mars provides considerably higher spatial resolution measurements (140-km block size) than did previous Mars missions (9) and permits the gravitational attraction of the SPLD and underlying crust to be resolved sufficiently for regional modeling for the first time (Fig. 2).

We found the best-fit density by calculating the predicted gravity field from the observed structures of the SPLD and of the crust and mantle. The key unknowns were the densities of the crust, mantle, and SPLD and the topography along the crust/mantle interface (the Moho). The densities of the martian crust and mantle were taken to be 2900 and 3500 kg m−3, respectively (10). Because it is not possible to solve simultaneously for both the SPLD density and the Moho topography, we represented the Moho beneath the SPLD by assuming that the topography before loading by the SPLD is in a state of partial isostatic compensation. The best-fit degree of compensation outside the SPLD of 91% was applied to the crustal topography beneath the SPLD to estimate the depth to the Moho. The lack of observed flexure in MARSIS profiles (8) suggests support by a thick lithosphere (11). We calculated the deflection of the Moho by the

Reference and Notes

25. MOLA topographic data at 1/228 degree per pixel grid spacing were used to simulate echoes from the cross-track region for each SHARAD subsurface sounding observation. Along-track sources were suppressed because SHARAD data processing achieves this by aperture synthesis.
28. The Shallow Subsurface Radar (SHARAD) was provided by the Italian Space Agency, and its operations are led by the INFOMC Department, University of Rome "La Sapienza." Thales Alenia Space Italia is the prime contractor for SHARAD and is in charge of in-flight instrument commissioning and of the SHARAD Operations Center. The Mars Reconnaissance Orbiter mission is managed by the Jet Propulsion Laboratory, California Institute of Technology, for the NASA Science Mission Directorate, Washington, DC. Lockheed Martin Space Systems, Denver, is the prime contractor for the orbiter.

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SPLD as in (12), using a fast Fourier transform approach (see supporting online material).

The contributions to the gravity from the topography along the Moho, crustal surface, and SPLD surface were calculated, accounting for the finite amplitude of the topography (13). The SPLD density was iterated to find the best fit between the modeled and observed gravity (14).

For the preferred case of zero flexure beneath the deposits, we found a mean density of 1220 kg m$^{-3}$, with a 95% confidence interval (CI) of 740 to 1780 kg m$^{-3}$ and a root mean square misfit over the SPLD of 22.9 mgal (1 gal = 10$^{-2}$ m s$^{-2}$) (Fig. 2). For a flexural approach (see supporting online material).

Reducing the crustal density to 2700 kg m$^{-3}$ reduces the SPLD density marginally to 1200 kg m$^{-3}$. The result is only weakly sensitive to the assumed degree of compensation, and thus the recovered density is not highly sensitive to the key unknowns.

As an independent check, we also performed an inversion for the SPLD density. We calculated model-gravity anomalies associated with the crust and mantle, assuming crustal and Moho topography and densities as noted above.

The residual gravity compared to the observed gravity was assumed to be due solely to the mass of the SPLD, which is a simplification because some of the variation is probably due to crustal sources. For this simple model, results yielded a model average density of 1290 kg m$^{-3}$, consistent with the forward model results.

The density of 1220 kg m$^{-3}$, taking into account surface spectral measurements (3, 4), is most simply explained by water ice with a silicate dust content of 15%. Though the 95% CI formally allows for the possibility of pure water ice, dust is observed at the surface (Fig. 1) of the SPLD, and in the subsurface, layering that probably reflects alternating ice and dust possibly emplaced during different climatic time periods is indicated by MRO sounding-radar profiles (15). Our result can be compared with a dust content of 0 to 10% inferred from the dielectric loss tangent of the SPLD measured by MARSIS (8). It also supports an earlier inference based on laboratory measurements of rheological properties (16) that the SPLD are mostly water ice rather than denser (1589 kg m$^{-3}$) CO$_2$ ice.

Despite the dustlike albedo and spectral signature over most of its surface, the martian SPLD are probably composed of relatively clean water ice. These deposits represent the largest known surface reservoir of water on Mars today and the largest in the inner solar system outside of Earth.

**References and Notes**

12. C. L. Johnson et al., Icarus 144, 313 (2000).
14. The observed gravity was filtered to subtract spherical harmonic degrees 2 and 3 to remove the effects of the Tharsis rise, and a cosine filter was applied to degrees 85 to 90 to reduce noise, whereas the modeled gravity was low-pass filtered to match the resolution of the observed field.
17. The MRO Radio Science Investigation is supported by the NASA Mars Program.

**Supporting Online Material**

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Fig. 52. References

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**Fig. 1.** MOLA shaded relief mosa-ic combined with color from Mars Global Surveyor imaging of Mars’ south polar region showing the residual ice cap (in white) within the smooth SPLD that overlie the cra-tered southern highlands. [Photo credit: NASA/MOLA Science Team]

**Fig. 2.** (A) Topography (7), (B) observed gravity, and (C) modeled gravity for the SPLD with the best-fit density of 1220 kg m$^{-3}$. Map windows are 40° by 40° in stereographic projection. (D) 95% CIs are indicated by dashed lines. RMS, root mean square. The result is only weakly sensitive to the assumed degree of compensation, and thus the recovered density is not highly sensitive to the key unknowns. As an independent check, we also performed an inversion for the SPLD density. We calculated model-gravity anomalies associated with the crust and mantle, assuming crustal and Moho topography and densities as noted above.

The residual gravity compared to the observed gravity was assumed to be due solely to the mass of the SPLD, which is a simplification because some of the variation is probably due to crustal sources. For this simple model, results yielded a model average density of 1290 kg m$^{-3}$, consistent with the forward model results.

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