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SUPPLEMENTARY NOTES

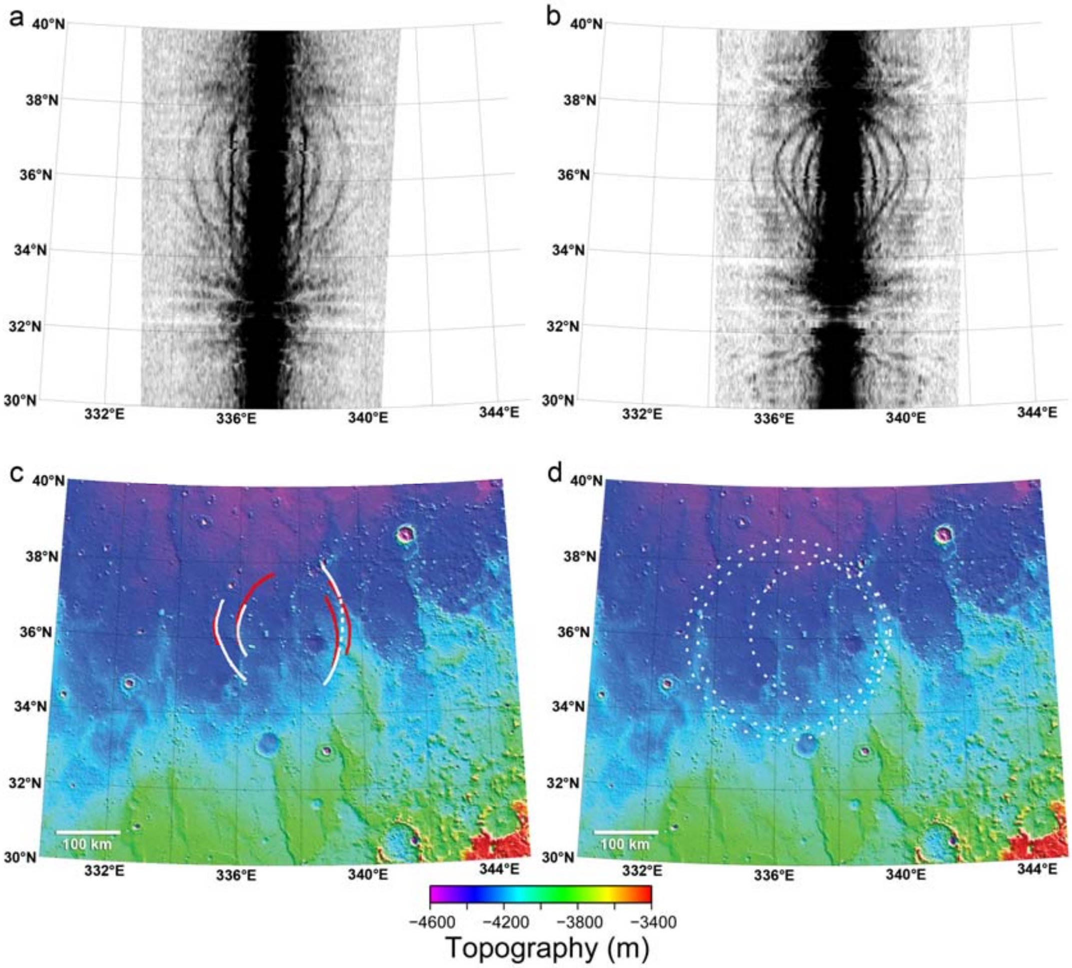
S1. MARSIS ANTENNA AND INSTRUMENT OPERATIONS

The MARSIS antenna is 40 m in length and radiates with a peak transmitted power of ~10 Watts[1]. The instrument has 1 MHz instantaneous bandwidth that provides a free-space range resolution of approximately 150 m. The typical spatial resolution is 10 to 30 km cross-track and 5 to 10 km along-track. The signal-to-noise ratio after summing, usually of 60-300 pulses at a pulse repetition frequency of 127 Hz, is ~30 to 50 dB. Subsurface sounding data are generally obtained when the spacecraft altitude is between 250 to 800 km.

MARSIS subsurface sounding data are greatly influenced by the ionosphere of Mars[2, 3]. Radar pulses can not reach the surface if the ionospheric plasma frequency is close to or above the sounding frequency. To avoid interference from the ionosphere, the instrument is generally operated when the spacecraft pericenter is on the nightside of Mars. Data are collected in the subsurface-3 mode which performs pre-summing onboard and returns complex spectra from three synthetic aperture (Doppler) channels for each of two frequency bands. Ground processing involves transforming the spectra into the time domain and correcting for phase distortion in the ionosphere[3]. Because of the high variability in the ionospheric phase distortion[3], the time delay of the initial surface return is corrected to agree with the MOLA topography along the orbit track. This allows direct comparison with MOLA derived surface clutter models, which aids in separating surface returns from subsurface returns.

S2. BURIED BASINS IN CHYRSE PLANITIA

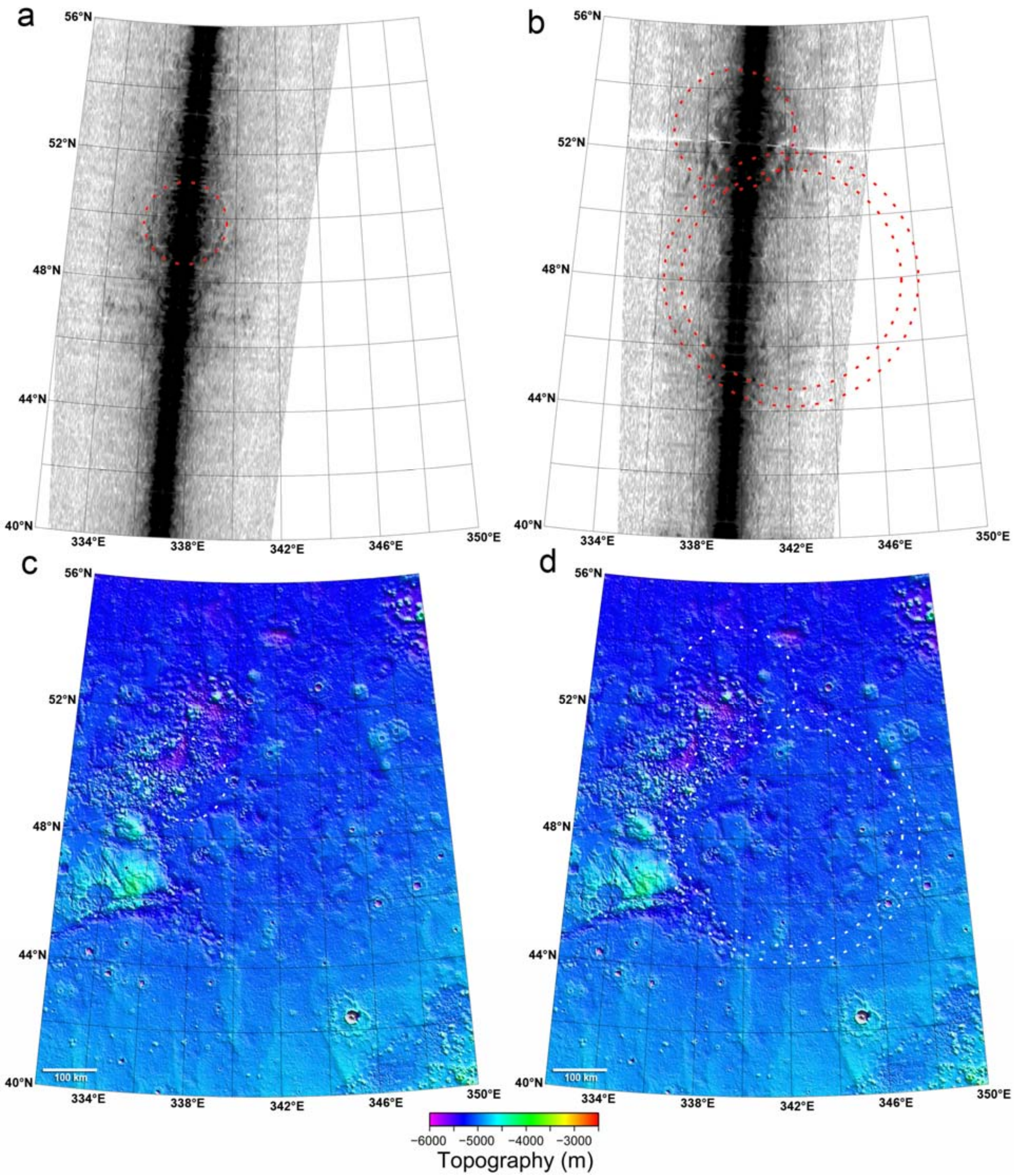
Fits to echoes in the ground-range projections suggest three possibilities; the echoes can be accounted for by a single ~220 km-diameter basin, a larger ~310 km-diameter basin, or two superimposed basins. A single ~220 km-diameter basin can encompass most of the overlapping parabolic echoes (Supplemental Note Fig. 1). Two parallel, overlapping sets of arcs separated by ~20 km are interpreted to be top and bottom near rim wall reflections of a buried basin ~290 to 310 km in diameter (Supplemental Note Fig. 1). Other interior echoes may be from rim wall slumps or a discontinuous peak ring structure. However, many of the echoes in the 1892 and 1903 radargrams appear to extend to the surface (intersecting with the surface return), inconsistent with a source for the echoes at or near the floor of the basin as would be expected for rim wall slumps or a peak ring. MOLA-based surface clutter models for orbits 1892 and 1903 show that the echoes can not be accounted for by topography.



Supplemental Note Fig. 1. Ground-range projections of radargrams for 1903 (a) and 1892 (b). The locations of overlapping echoes (c) and the inferred buried basins (d) are shown on MOLA color coded shaded relief maps. Overlapping echoes (c) in the ground-range projection of 1903 (white) and 1892 (red) radargrams indicate returns from the same subsurface reflectors. Fits to the projected arcs indicated by dashed white circles (d) show the approximate locations of two buried impact basins, an ~220 km-diameter basin and an ~310 km-diameter basin. Other echoes may be attributed to a possible peak ring structure.

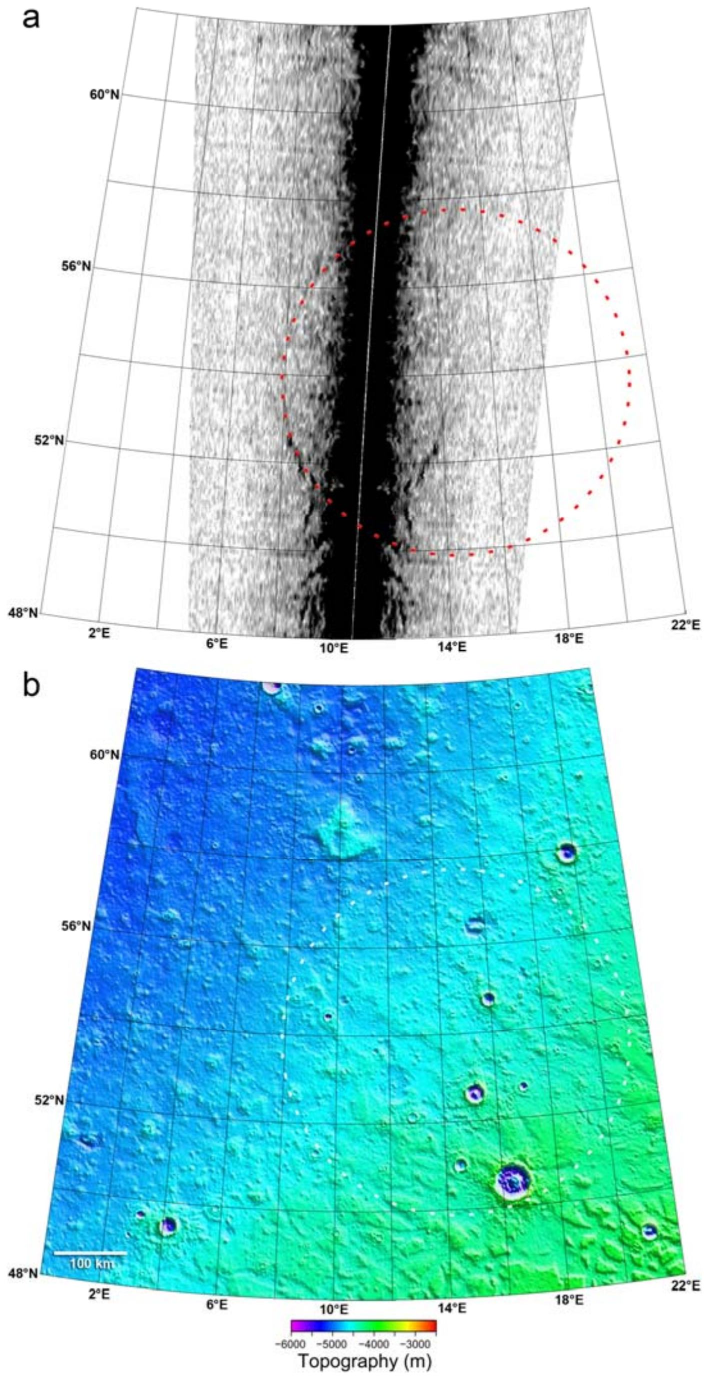
S3. BURIED BASINS IN ACIDILIA, AMAZONIA, ELYISUM, AND UTOPIA PLANITIEA

Parabolic echoes in MARSIS data often consist of a single echo or pairs of echoes that can be either continuous or discontinuous. A broad, diffuse parabolic echo in orbit 1881 indicates buried basin in Acidilia Planitia ~400 to 470 km in diameter (Supplemental Note Fig. 2). The MARSIS echoes are assumed to originate from buried (near-surface) structures, because there is no indication of a broad, parabolic echo in the MOLA-based clutter model for orbit 1881. The basin corresponds to a roughly circular topographic depression. The westernmost extent of the topographic depression is marked by mesas of the Acidalia Mensa (see 4). Two smaller basins, one ~150 km in diameter and the other ~220 km in diameter are suggested by single, discontinuous parabolic echoes in MARSIS orbits 1881 and 1903 (Supplemental Note Fig. 2). Circular fits to the echo in 1881 suggests that the orbit track does not cross the basin center. The left/right ambiguity in the MARSIS data thus does not allow a unique determination of the location of the center of the basin. However, fits to the echo in 1903 suggest the orbit does cross near the center of the 150 km-diameter basin. Both basins appear to be superposed on the northwestern rim of the 470 km-diameter basin.



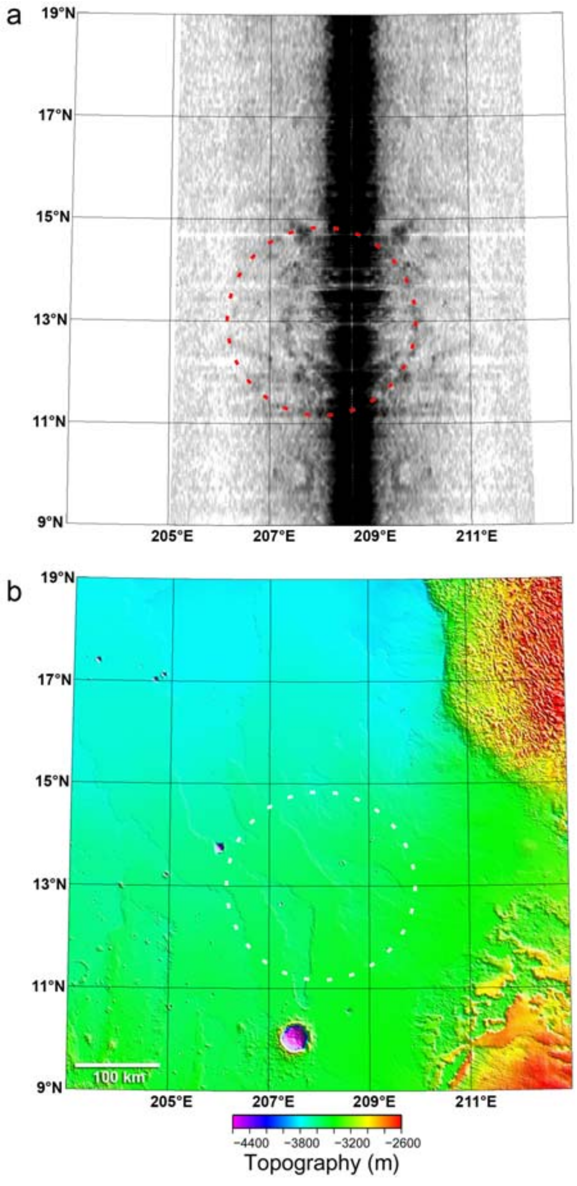
Supplemental Note Fig. 2. Ground-range projections of radargrams for 1903 (a) and 1881 (b). The locations of inferred buried basins (red dashed circles in 2a, b and white dashed circles 2c, d) are shown on the ground-range projections and on MOLA color coded shaded relief maps of part of western Acidalia Planitia.

Evidence of a second large basin in eastern Acidalia Planitia is found in MARSIS orbit 1899. A single, generally continuous parabolic echo in 1899 suggests another ~470 km-diameter basin (Supplemental Note Fig. 3). There is no perceptible expression of this basin in the MOLA shaded relief.



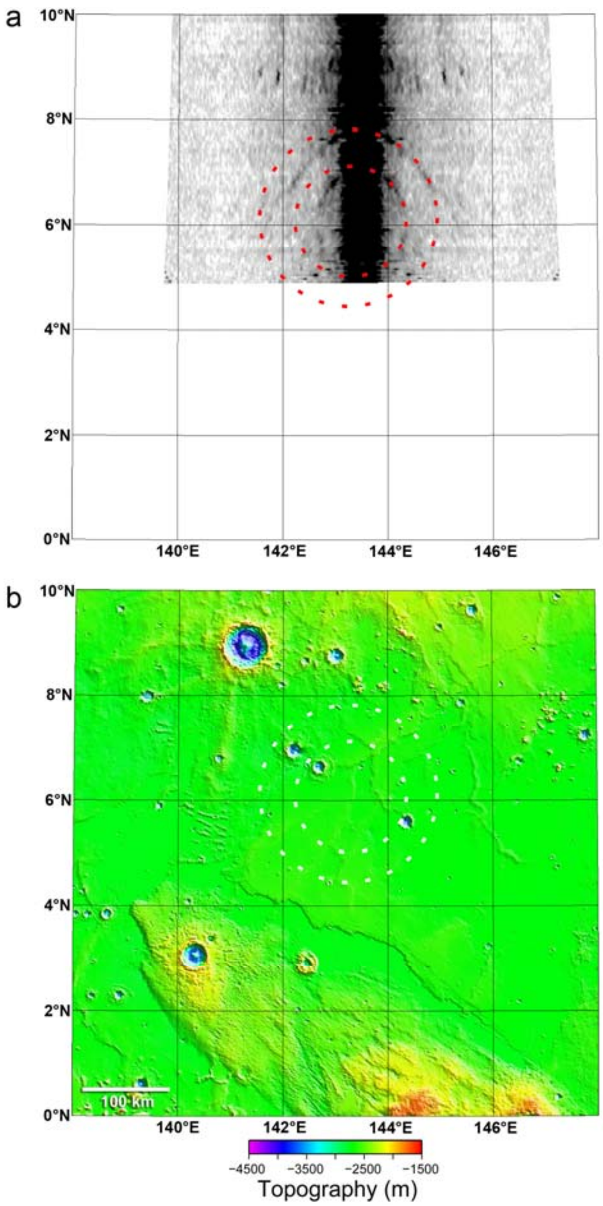
Supplemental Note Fig. 3. Ground-range projection of the radargram for 1899 (a) with the location of an inferred buried basin shown on MOLA color coded shaded relief part of eastern Acidalia Planitia (b). The location of the inferred buried basin is shown by the red dashed circle in 3a and the white dashed circle 3b.

A third basin in southern Amazonis Planitia is suggested by a discontinuous parabolic echo in orbit 1875 (Supplemental Note Fig. 4). The best fit to the echo indicates an ~210 km-diameter buried basin with the orbit track offset from the basin center. The left/right ambiguity in the data does not allow a unique determination of the basin center.



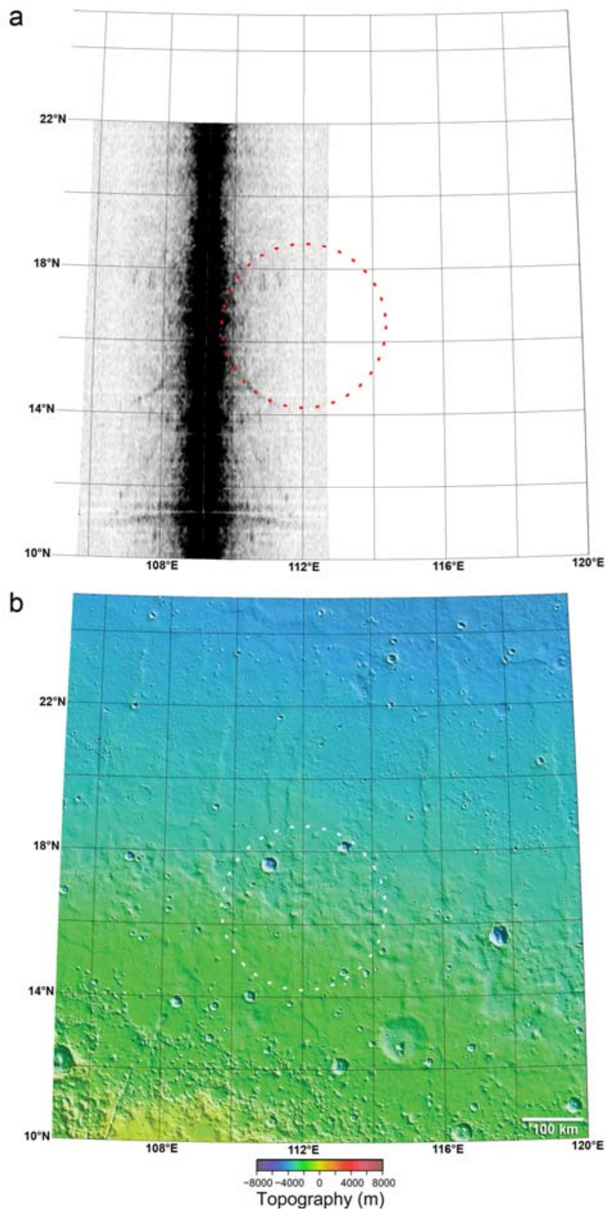
Supplemental Note Fig. 4. Ground-range projection of radargrams for 1875 (a) with the location of an inferred buried basin on MOLA color coded shaded relief of part of southern Amazonis Planitia (b). The location of the inferred buried basin is shown by the red dashed circle in 4a and the white dashed circle 4b.

MARSIS sounding data over the volcanic plains of Elyisum Planitia indicate a buried basin under a sequence of Late Hesperian to Late Amazonian lava flows. The ground-range projection of a pair of discontinuous parabolic echoes in orbit 1872 suggests a basin with an outer diameter of ~200 km and an inner diameter of ~120 km (Supplemental Note Fig. 5). The difference in diameters is too large to be accounted for by reflections from an upper and lower rim wall and the interior echo does not intersect the surface return. This suggests the source of the interior echo may be from a peak ring structure.



Supplemental Note Fig. 5. Ground-range projection of radargrams for 1872 (a) with the location of an inferred buried basin on MOLA color coded shaded relief of part of southern Elysium Planitia (b). The locations of the inferred buried basin rim wall and a possible peak ring structure are shown by the red dashed circle in 5a and the white dashed circle 5b.

The concavity of the parabolic echoes in radargrams described above is concave up, indicating that the MARSIS orbits passed over the interiors of the buried basins. If the MARSIS orbit passes outside a basin, the exterior rim wall echo is expected to have the opposite concavity; concave down. Such an echo is observed in the sounding data over the lowlands of southern Utopia Planitia (Supplementary Note Fig. 6), just north of the dichotomy boundary in Amenthes. The echo in orbit 1887 suggests a ~270 km-diameter basin buried in part beneath the knobby and fretted terrain of Nepenthes Mensae.



Supplemental Note Fig. 6. Ground-range projection of radargrams for 1887 (a) with the location of an inferred buried basin on MOLA color coded shaded relief of part of southern Utopia Planitia (b). The location of the inferred buried basin is shown by the red dashed circle in 6a and the white dashed circle 6b.

S4. ESTIMATE OF MARSIS COVERAGE OF THE NORTHERN LOWLANDS

During the initial phase of MARSIS operations, 34 orbits with sufficient signal-to-noise crossed the northern lowlands. The area of the lowlands surveyed by MARSIS is strongly dependent on the cross orbit track distance beyond which basins are not likely to be detected. The maximum distance from the basin rims to the orbit tracks for the eleven MARSIS basins ranges from 30 to 130 km (mean = 90 km, standard deviation ≅ 29 km). Thus, we estimate the area covered using a cross-track distance of 180±58 km (2× the mean and standard deviation due to the left/right ambiguity). Orbit segments were limited to those where the spacecraft altitude was <500 km because no parabolic echoes have been detected at greater altitudes.

SUPPLEMENTARY FIGURE AND LEGEND

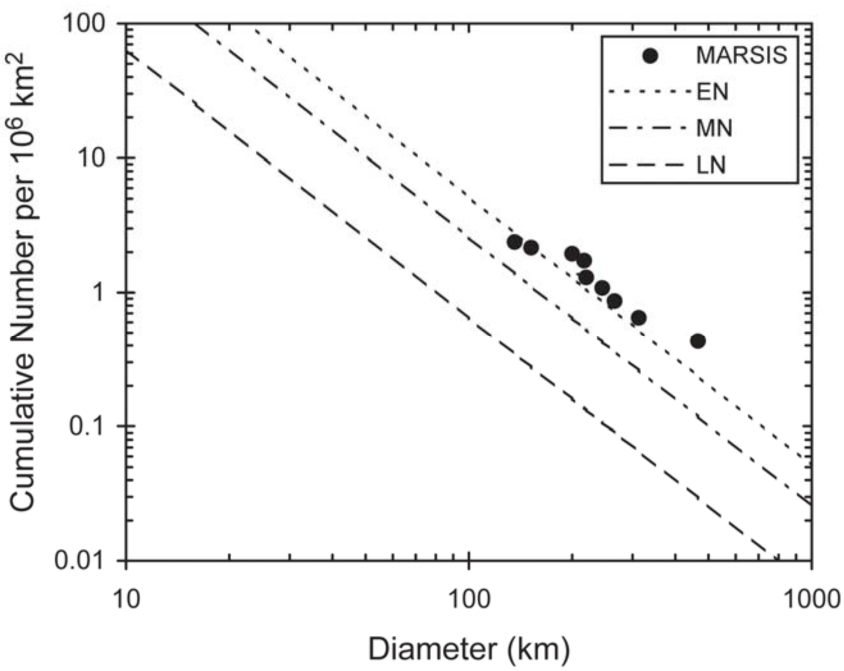


Figure S1. Cumulative frequency plot for MARSIS basins in the northern lowlands of Mars. The dashed lines show the Late Noachian (LN), Middle Noachian (MN), and Early Noachian (EN) boundaries based on crater counts of Tanaka[5] extrapolated to larger diameters with a -2 power law. Most of the MARSIS basins plot above the Early Noachian boundary.

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