STRUCTURES WITHIN MARTIAN POLAR CAPS REVEALED IN SHARAD 3-D RADAR VOLUMES.

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Introduction: We will present two three-dimensional (3-D) volumes of radar data, each created from observations by the Shallow Radar (SHARAD) sounder on over 2000 orbits of the Mars Reconnaissance Orbiter (MRO) [1]. These volumes encompass Planum Boreum and Planum Australe, the domes of ice-rich deposits that form the polar caps of Mars. The volumes provide new and improved views of the internal structures from the surface to the base of the deposits at depths of ~2–4 km. Features of the cap interiors that required painstaking effort to identify and map with 2-D radargrams (images of power along track vs. delay time) are readily identified in the 3-D data volumes, even in the preliminary southern volume with no geometric corrections applied. The completed volume for Planum Boreum (Fig. 1) reveals new features below large regions that were largely undecipherable in 2-D radargrams due to interfering off-nadir surface returns from polar troughs. In addition, we have identified likely buried impact craters within the ice.

SHARAD Observations: SHARAD operates with a 10-MHz bandwidth centered at 20 MHz. Range resolution is 15 m in free space, ~8 m in nearly pure water ice (expected for much of the icy layered deposits [2-4]), and still finer in ice with a greater proportion of lithic inclusions. With the MRO orbit altitude of 250–320 km, lateral resolution at the surface is ~3–6 km, reducible along track to 0.3–1.0 km in processing [5]. High-power returns indicate a strong contrast in dielectric properties of materials at a geologic interface. In polar terrains, reflections likely arise from different degrees of dust or sand loading between adjacent ice layers [3, 4, 6].

Off-nadir returns. Topography (e.g., hills, crater walls, polar troughs) off of the spacecraft's nadir track often yield reflections, termed *clutter*, that can be difficult to distinguish from nadir returns. Internal structure—such as dipping or folded layering—may result in the mis-location of features. The use of synthetic-aperture focusing in creating 2-D radargrams compresses the response from along-track scatterers but not from cross-track scatterers, leaving a structural blur in the data. In addition, the signal-to-noise ratio (SNR) can be quite low when material properties lead to substantial scattering or absorption.

SHARAD studies typically have used elevation data to produce synthetic radargrams for identifying surface clutter [e.g., 4, 7], but this technique does not address clutter obfuscation of nadir subsurface returns, mis-positioning of internal structures, and signal losses. Fortunately, dense radar coverage allows treating the data collectively in a volume and applying an imaging process that will largely correct structural distortion effects by placing signals in their correct locations in 3-D space while improving their SNR.

Time delays. Prior to applying the 3-D imaging process, the along-track data must be corrected for any relative time delay introduced by the variable orbit altitude and the Martian ionosphere. While accurate ephemeris data enables a straightforward altitude correction, we found that ionospheric delays vary substantially along track and from one orbit to another. A major effort produced an accurate method for estimating those delays [8], but residual delays have led to some degradation of vertical resolution in the volumes relative to that of the 2-D input data. An effort is underway to eliminate the residuals and improve 3-D resolution.

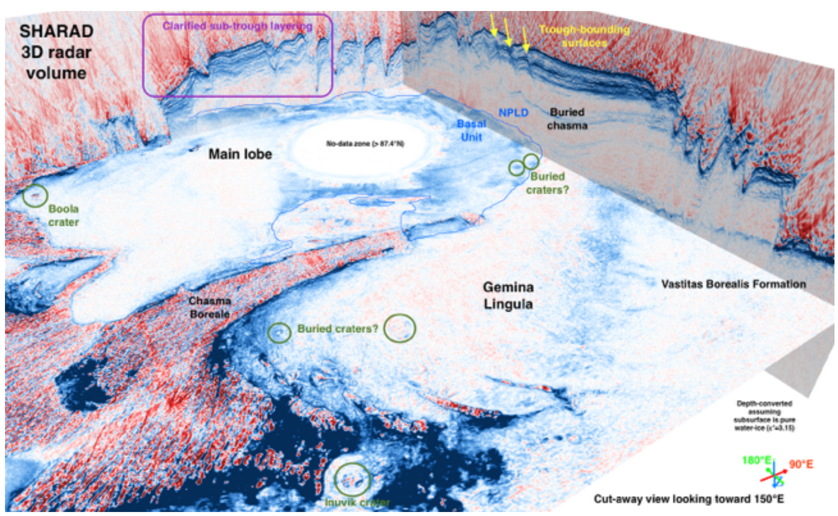

Figure 1. Cut-away view into a SHARAD 3-D migrated and depth-converted volume showing radar return power (blue high, red low) in the interior of Planum Boreum. Previously mapped structures—buried chasma [15], *boundary of the basal unit* [18], *trough bounding surfaces* [20]*—are readily seen and new features—sub-trough layering* [25], *possible buried impact craters—are newly revealed. The no-data zone is 310 km across and the stack of NPLD layers to the right of the buried chasma is 2 km thick.*

3-D Imaging Process: The occurrence in seismic data of the geometric and loss concerns discussed above led to the development of migration processing, a mathematical inversion that converts the recorded seismic image to one in which subsurface features appear in their proper positions [9, 10]. Migration also improves resolution by collapsing backscattered wave-field energy to the scattering point. Many migration algorithms have been developed to account for various degrees of subsurface complexity [11-14]. Applied to radar data, 3-D migration addresses many limitations of 2-D radargrams. For example, clutter returns treated as noise in 2-D become useful signals in 3-D, enhancing the image upon being repositioned to their source locations. Interfering returns are unraveled and internal structures are properly positioned. In addition, SNR improves by a combination of band-limited, spatial-domain processing and incoherent summation of reflectors seen in adjacent and crossing orbit tracks.

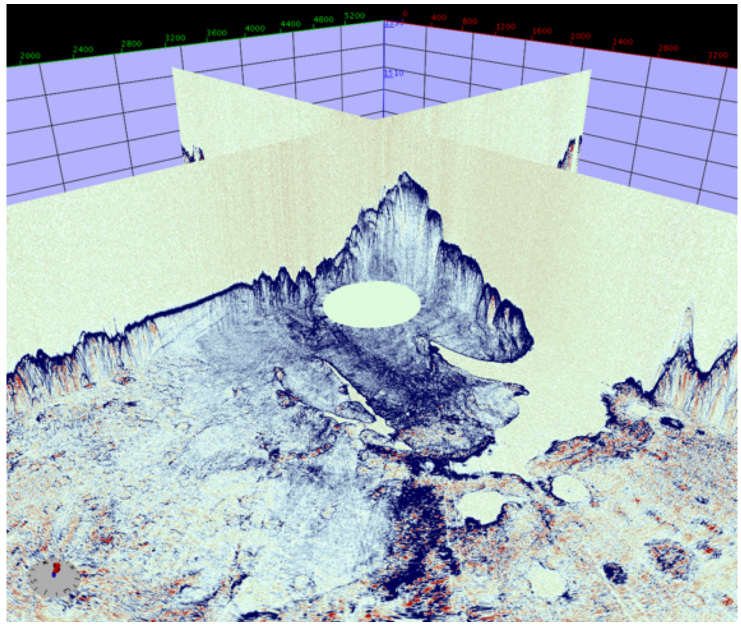

Figure 2. Cut-away view into a SHARAD 3-D volume showing radar return power (blue high, red low) in the interior of Planum Australe. Numerous craters at the surface—and perhaps some fully buried in the ice—are visible, as is interior layering of the SPLD, including CO_2 ices [19]. *No migration processing has been applied. The no-data zone is 310 km across and the vertical dimension shows 17 µs of delay time (~2.5 km).*

Results and Discussion: The 3-D volume enables views into the interior of Planum Boreum (Fig. 1) that are difficult or impossible using separate 2-D profiles. The delay-time and depth slices allow identification of structural elements in plan view, including circular patterns associated with known impact craters that are repeated elsewhere in the volume without surface expression, strongly suggestive of buried craters. One must be cautious with this interpretation because quasi-circular planforms at the surface are also associated with some polar troughs and are not impact-related. The correction of clutter and proper positioning of trough bounding surfaces [16] has been particularly effective for Planum Boreum, notably supporting the mapping of a shallow unconformity that has been associated with the most recent retreat of mid-latitude glaciation [17]. In the preliminary Planum Australe volume, many other crater-like structures are evident, consistent with the notion that these deposits are an order of magnitude or more older. Migration processing will sharpen this view, and the expected improvement in SNR may reveal structures that are missing or very faint in 2-D profiles.

The clarified view of the polar-cap interiors provided by the SHARAD 3-D volumes promises to advance our ability to map out the interior structures and infer the history of their emplacement. A full assessment of likely buried craters may provide a means to date the deposits that is independent of climate models. Achieving these objectives would be a major advancement toward the overarching goal of linking the geologic history of the polar layered deposits to climate processes and their history.

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