RADAR SOUNDING OF OPEN BASIN LAKES ON MARS.

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Introduction: "Open basin lakes" (OBLs) have both inlet and outlet channels where surface water is thought to have once flowed [1]. A total of 224 OBLs are found throughout the southern highlands [1, 2]. We conducted the first comprehensive survey of SHARAD radar observations over OBLs to assess their stratigraphic structure and their geologic properties affecting the radar signal. Many of these OBLs are of particular interest because of their candidacy as future landing sites for missions searching for formerly habitable environments.

SHARAD Survey of Open Basin Lakes (OBLs): We did not find convincing evidence of subsurface radar reflectors in all but four of the 937 radargrams surveyed [3]. This is somewhat surprising because many of the lakes are known to contain layered sediments and volcanics [1]. To better understand what might prevent the detection of subsurface interfaces within the OBLs, we conducted new detailed studies of SHARAD radar data (414 nightside radargrams) and surface characteristics within a subsample of OBLs (10%, N=26) chosen to be representative of the global population. The subsample incorporates basin sizes spanning the complete range of OBLs from ~ 50 km^2 to the largest at 5×10^5 km^2, and over half of the basins (N=15) have been resurfaced by volcanic material [2].

Methods: For each basin, we developed methods for testing for the following factors: 1) Deterministic and statistical clutter (roughness), 2) Volumetric scattering, and 3) Surface hydration.

Deterministic Clutter. We developed a new, simple quantitative proxy for predicting the degree of clutter in each radargram that arises from large topographic facets. We used a directionally modified "Root Mean Square (RMS) height parameter" calculated from MOLA gridded topography. These RMS height values are weighted by the absolute sine of slope aspect, determined from the MOLA GEDR product to more greatly weight east or west facing slopes (slope aspects of 90º and 270º as measured clockwise from north); north and south-facing slopes result in parameter values of zero. The RMS Height Parameter was calculated as the average of these weighted RMS heights falling within a 25 km buffer surrounding the SHARAD ground-track.

Statistical Clutter. Statistical clutter (diffuse scatter from small-scale roughness elements) was represented by calculating a SHARAD roughness parameter after the methods described in [4]. The roughness parameter estimates the relative degree of topographic roughness at the 10 to 100 m scale. SHARAD roughness parameter values typically range from 2 (smooth) to 8 (rough) [4].

Verification of the Cutter Proxy. The radargrams were visually classified into low, moderate, and high clutter groups based on the concentration of clutter features identified in the radargram and associated cluttergram. A low visual clutter rank had few cross-track surface echoes, making detection of subsurface reflectors more likely (Fig. 1). High visual clutter ranks corresponded to radargrams where any subsurface reflector is likely to be entirely obscured. A moderate clutter rank had more cross-track echoes than those with a low rank. Identification of a reflector is still possible here, but there is an increased likelihood that a reflector will be obscured. We find that the RMS height parameter correlates well with our visual assessment of clutter with corresponding values of 4.5±1.7 m, 7.4±3.2 m, 13.5±9.3 m for low, moderate, and high clutter by taking the median of each visual clutter rank with upper and lower bounds determined by the interquartile range.

Volumetric Scattering and Surface Hydration. We examined a recent global compilation of hydrated mineral detections by CRISM [5] for evidence of their presence in the surface of the OBLs. Additionally, we examined available images from the MRO Context Camera (CTX) [6] and several High Resolution Imaging Science Experiment (HiRISE) images [7] in order to assess possible sources of volumetric scattering such as internal fracturing or discontinuous density variations.

Results: Our observations show that OBLs possess abundant smooth terrain that results in many radargrams with low clutter that should be favorable for detection of subsurface interfaces. We predict that radargrams with the least clutter and that are most favorable for identifying subsurface interfaces will fall within a region of low RMS height parameter (0-6 m) and low to moderate SHARAD roughness (2-5) (Fig. 2). For the entire population of OBLs, 249 radargrams (23.2%) covering 36 OBLs fall within this most favorable region.

In contrast, radargrams least favorable to detections are predicted to fall within a region of high RMS height parameter (>14 m) and spanning the full range of SHARAD roughness (2-8) (Fig. 2). A total of 171 radargrams (15.9%) from 56 OBLs fall within this least favorable region. Those that remain (*N* = 278) covering 70 OBLs have moderate RMS height values (6-9 m) that are predicted to have intermediate clutter characteristics.

Volumetric Scattering and Surface Hydration. We found that only two basins in our subsample had evidence of fracturing in MRO CTX images that we interpret as filled fractures exposed by differential erosion. Other pockets of fractures appear concentrated near the southeast rim of the basin. Their isolated occurrence suggests that these fractures are not pervasive throughout the unit or have not been preserved.

Alternatively, observations from the radargrams themselves may reveal the influence of volumetric scattering. We find that 91% of the radargrams in our subsample had a “rainfall” (downrange echo power) effect that we suggest may be related to internal scattering (Fig. 1).

Only four basins in the subsample contain exposed hydrated minerals using mapped CRISM detections from [5]. While it is possible that hydrated minerals may be obscured by dust or occur below the surface, many volcanically resurfaced lakes have clear basaltic signatures suggesting little alteration by water after emplacement of the volcanic material [2]. This suggests that hydrated minerals exposed at the surface or in the near-subsurface play a minor role in the lack of observed OBL subsurface reflectors.

Conclusions: Despite evidence of stratigraphic layering from orbital observations, only one OBL (Lake 218) showed evidence of a subsurface radar reflection. Detailed examination of SHARAD radar observations and surface geology at the remaining OBLs suggest that surface clutter and hydration alone are unlikely explanations for lack of detections in the smooth and unaltered interiors of many OBLs. Although surface expressions of fracturing or layer characteristics are limited, more likely candidates for radar attenuation are volumetric scattering or scattering off rough subsurface interfaces. A lack of a dielectric contrast or a deep reflector are also possibilities, but prior studies have shown that SHARAD can detect hundred-meter deep interfaces between sediments and volcanic materials [8,9]. Further investigation and modeling will be necessary to provide more insight into the complex Martian subsurface of these basins and the southern highlands.

References: [1] Fassett, C. I., and Head, J. W. (2008) *Icarus*, 198, 37-56; [2] Goudge, T. A., et al. (2012) *Icarus*, 219, 211-229; [3] Shoemaker, E. S., et al. (2017) *LPS XLVIII* #1658; [4] Campbell, B. A., et al. (2013) *JGR*, 118, 436–450; [5] Carter, J., et al. (2013) *JGR*, 118, 831-858; *JGR*, 116, E03001; [6] Malin, M. C., et al. (2007) *JGR*, 112, E05S04; [7] McEwen, A. S., et al. (2007) *JGR*, 112, E05S02; [8] Campbell, B. A., et al. (2008) *JGR*, 113, E12010; [9] Morgan, G. A., et al. (2015) *GRL*, 42, 2015GL065017.

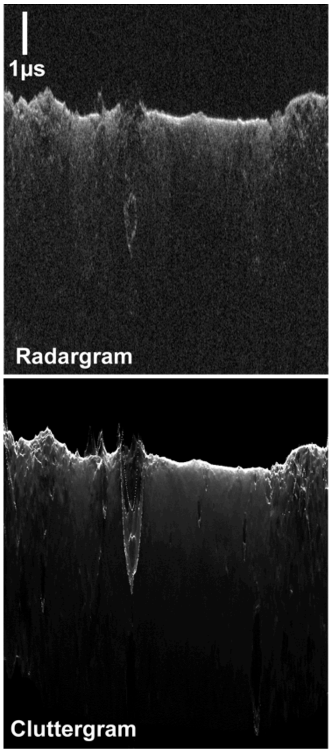

Figure 1. Low clutter ranks correspond to few cross-track surface echoes. Radargram 2630002 in Antoniadi is ranked low in clutter with an RMS height parameter value of 6.3 m. The diffuse “rainfall” is present at shorter time delays in this radargram, slightly lower in power than the clutter.

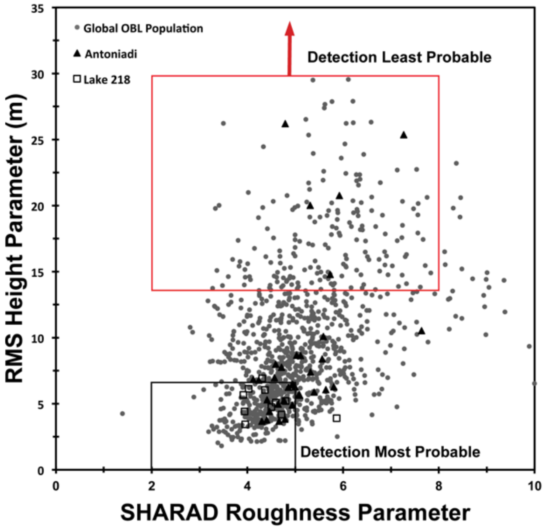

Figure 2. Radargrams with less clutter (black box) should be more favorable for the detection of subsurface interfaces than high-clutter radargrams (red box). This figure shows the RMS height parameter versus SHARAD roughness parameter [4] for nightside radargrams crossing outlines of all OBLs [1]. Lake 218, which shows reflectors, and Antoniadi are also plotted.