A Ground Penetrating Radar Lunar Analogue Field Campaign in the Haughton Impact Structure, Canada

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Introduction

Ground-penetrating radar (GPR) has been widely cited as an important scientific tool for subsurface and near-surface exploration missions (Arman, 2000). In support of GPR technique testing for lunar subsurface exploration, a series of overlapping 2D and 3D GPR surveys were conducted over impact melt rocks at the Haughton impact structure, Devon Island, Canada. Figure 1. This complex crater is estimated to be 30 Ma and 23 km in diameter (Lee and Osinski, 2005)

Figure 2 (above): Air photo of survey location. The grey unit is larger of the two, a calcite-dominated clast-rich melt rock. Survey location is marked in the red square. The site was selected to maximize the effect of major structural features nearby, such as fault scarps and polygonal terrain.

GPR surveys were carried out using a PulsedBlow Pro GPR system from Sensors and Software. This unit was equipped with interchangeable 200, 100, and 50 MHz antennae, a cart with electronics, and a PulsedBlow 400V transmitter. The primary objective was to observe the effect of scattering on effective depth of signal penetration as a predictor for lunar return.

2D Surveys

2D surveys were conducted at 200, 100, and 50 MHz on the baseline to provide an estimate for noise and 2D depth of penetration. These lines are presented in sequence in Figures 6, 7, and 8.

Figure 3 (above): Surface location looking East along the baseline (+Ydir). Figure 4 (left): CMP survey along baseline at 200MHz. Top layer velocity (active layer) was mismatched with the hyperbola shown to be 0.112 km/μs. Figure 5 (left): CMP survey along baseline at 200MHz. Second layer velocity (permafrost) was mismatched with the hyperbola shown to be 0.110 km/μs.

The target consisted of calcite-dominated clast-rich impact melt rock (Lee and Osinski, 2005) with permafrost at depths measured in meters at less than one metre. The target rocks were chosen as a physical analogue to lunar geophysical conditions: the electrical permeability of ice (κ=2.3) and calcite (κ=9) produces a better match for lunar geophysical conditions (κ=3-10) than liquid water (κ=106) bearing analogue sites (Heiken et al., 1997). Chung et al. 1970; Heiken et al., 1991).

Velocity Measurement

Additional 2D surveys were performed to compare the response of the target area to those of the nearby intact dolomitic limestone. These surveys were performed at 100 MHz only and are presented for 400 m heading directly North from the grid origin (perpendicular to the baseline). As seen in Figure 7 and 8, the signal response from depth becomes increasingly coherent as the survey transitions onto the dolomitic limestone megadikes. A ground-penetrating radar Lunar Analogue Field Campaign in the Haughton Impact Structure, Canada.

3D Surveys

The main survey at this location was a multi-frequency 3D survey over a 30x30m-grid. The baseline for this grid is the same as the CMP and 2D baseline surveys. The grids for the various frequencies are shown in Figure 9. Survey parameters are Table 1. Example depth slices are plotted in Figure 10 and are labelled for 100 MHz, 50 MHz and 20 MHz. For comparison, Figure 11 shows a single slice at 200 MHz. The 200 MHz slice shows subtle features on the left side while the single slice at 200 MHz shows the larger dichotomy running diagonally across the survey area. The 50 MHz slice shows several linear features that could be fractures.

Figure 6: 2D survey all tips to bottom; 200, 100 and 50 MHz. Slices are equispaced to allow for comparison between different frequencies. Depth estimate is assuming single layer at 0.110 km/μs and does not take into account a ~2 m slow layer (0.076 km/μs), which slows down delays by an estimated half a meter. Station spacings are 20, 25, 50 and 75 cm respectively. Stacking via Dynex.

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<table>
<thead>
<tr>
<th>Peak Frequency</th>
<th>Antenna Separation</th>
<th>Station Spacing</th>
<th>Line Spacing</th>
<th>Tilt Error</th>
</tr>
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<tbody>
<tr>
<td>200 MHz</td>
<td>10 cm</td>
<td>10 cm</td>
<td>10 cm</td>
<td>162</td>
</tr>
<tr>
<td>100 MHz</td>
<td>25 cm</td>
<td>10 cm</td>
<td>15 cm</td>
<td>162</td>
</tr>
<tr>
<td>50 MHz</td>
<td>50 cm</td>
<td>25 cm</td>
<td>15 cm</td>
<td>162</td>
</tr>
</tbody>
</table>

The main survey at this location was a multi-frequency 3D survey over a 3x3x3m-grid. The baseline for this grid is the same as the CMP and 2D baseline surveys. The grids for the various frequencies are shown in Figure 9. Survey parameters are Table 1. Example depth slices are plotted in Figure 10 and are labelled for 100 MHz, 50 MHz and 20 MHz. For comparison, Figure 11 shows a single slice at 200 MHz. The 200 MHz slice shows subtle features on the left side while the single slice at 200 MHz shows the larger dichotomy running diagonally across the survey area. The 50 MHz slice shows several linear features that could be fractures.

Analysis

The 2D plots show continuous interfaces that vanish at 2.5, 5 and 9 metres for 200 MHz, 100 MHz and 50 MHz plots, respectively. When comparing the 4 MHz penetration for 100 MHz in the target lithology to the 18 m penetration in the neighbouring unit, the effect of the brecciation on the signal propagation becomes apparent.

The 3D plot shows that faults can be traced to depths greater than what is visually apparent on the 2D plots. Depth of resolution in 3D is increased slightly to 3.2, 6 and 10 metres. While this suggests the usefulness of 3D imaging in improving depth resolution in a scattering medium, it is still less at 90 MHz than the 200 MHz in the neighbouring unit.

Additional analysis yet to be completed include: measuring the electrical conductivity and electrical permittivity in samples with varying water content and temperature. These data will be used to create a model for use in 3D GPR simulation to attempt to confirm the hypothesis that the scattering material is acting as an additional source of attenuation.

Conclusion

Physical analogue testing at the Haughton Crater suggests that signal scattering in brecciated materials significantly attenuates GPR. As a consequence, the depth of GPR usefulness for lunar exploration may be reduced in areas of highly brecciated material.

The addition of 3G-PG data can help to improve the effective depth of penetration by approximately 20% in visual plots, however this requires significant additional data collection.

Additionally, performing these analogue tests in an environment that is electrically similar to the lunar surface will help to confirm that the reflections seen are not simply strong reflectors from a water filled fracture or similar interface.

References


