DETERMINATION OF LUNAR REGOLITH THICKNESS AND EXPLORATION FOR FROZEN LUNAR WATER USING HUMAN-OPERATED GROUND-PENETRATING RADAR.

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Introduction: The thickness of the lunar regolith and potential for frozen water are important considerations for future lunar outposts. However, the thickness of the regolith is largely unknown and the presence of water ice has yet to be directly detected at or beneath the surface. A rapid and economical geophysical method to determine both the thickness of the lunar regolith and possibly identify the presence of water ice is surface ground-penetrating radar (GPR). Although GPR methods have been proposed for future missions, they rely on lower-resolution orbiting platforms or unmanned rovers. We believe that astronaut-operated surface GPR experiments during the early lunar sortie missions are superior to unmanned experiments because of the high resolution available with surface experiments, ability to collect common midpoint (CMP) velocity soundings, rapidity of acquisition, longer profiles collected at a variety of target depths, flexibility of operation, and ability to take advantage of unplanned scientific opportunities. The astronauts would collect profile GPR data from their rover or by hand as they move between other experiments. They would subsequently collect CMP velocity soundings with two movable antennas over several good data return areas, or interesting anamolous zones, for subsequent depth conversion of the profile data.

GPR Method: The GPR method consists of sending an electromagnetic radar pulse in the megahertz to gigahertz frequency range down into the ground. A single trace (or a series of traces from the same location that are added or "stacked" together) is then recorded for a certain length of time, with reflections appearing as the pulse echos off the boundaries between sediment or rock units below (Figure 1).

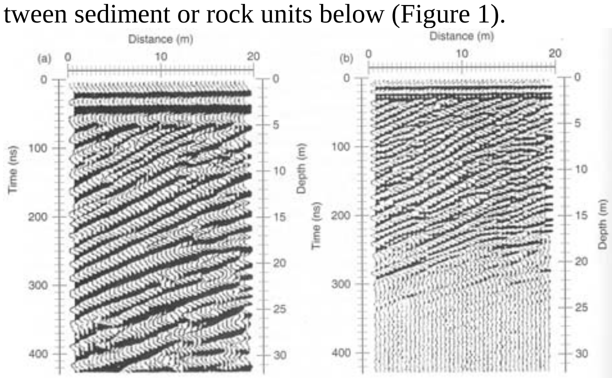

Figure 1. Ground-penetrating radar data collected with (a) 50 MHz antenna, and (b) 100 MHz antenna. Modified from [1].

The amplitude of the reflections depend on the contrast in dielectric constant between the layers. The greater the contrast, the greater the amplitude of the reflections. Typically, the data are acquired along a profile line or grid, with a relatively constant distance between traces or grid points. The data are generally displayed in a time section (Figure 1) much like reflection seismic data. When a grid of data are collected, a 3-D data cube can be displayed as well.

Proposed Lunar GPR Profile Package: Based on present day GPR equipment, and on terrestrial studies undertaken to date with this equipment, it is likely that the lunar GPR equipment will consist of two packages modified from existing units for the lunar environment. Each of these packages would likely be powered by 12 Volt batteries or something similar, possibly recharged using solar cells or another source of energy. Position information for the data will be provided by a wheel odometer, tape measure, lunar surface navigation system, or a combination of these. The first package will consist of a monostatic or fixed bistatic antenna setup that will be towed behind the lunar rover or an astronaut (Figure 2). This setup will allow a quick

Figure 2 (a). Fixed bistatic [2].

Figure 2 (b). Monostatic [2].

change between one antenna frequency and another to allow for different penetration depths and resolutions. The three antenna frequencies that will likely be used in this setup are 250 MHz, 500 MHz, and 1000 MHz. It is also possible that acquisition using three or four different antenna frequencies can occur simultaneously, thus saving astronaut crew time while maximizing the depth of penetration and resolution (Figure 3). The GPR unit would also consist of a combined digital video logger and control module that would reside on the lunar rover or be carried by an astronaut. The data could be viewed in real time by the astronauts, but would also be stored in the digital video logger for later processing, viewing, and interpretation by the astronauts and ground crew. The astronauts would be trained to recognize various reflections and diffractions showing up on the screen, allowing them to identify the base of the regolith, layering beneath it, and any anomalous reflections or diffractions potentially caused by frozen water, lava tubes, or buried craters. They could also seek out the best spots for other subsurface studies such as core holes and trenches. It is expected that the GPR data will often be acquired while the astronauts are traveling from one location to another to deploy or run other experiments, thus minimizing crew time.

Figure 3. Multichannel bistatic configuration [2]

Proposed Lunar GPR CMP Package: The other package will consist of one or more pairs of detached bistatic GPR antennas ranging from as low as 12.5 MHz to 1000 MHz or higher. These will be used for the CMP velocity sounding experiments (Figure 4) and other profiles needing antennas that may be too large to safely attach to the lunar rover. For the CMP velocity sounding experiments to work properly, two astronauts are <u>required</u> to move the antennas a fixed equal distance progressively farther away from a central location (the CMP) each time a trace is recorded. The farthest the two antennas must be separated and the distance interval in which they are moved depends on the frequency and penetration depth of the antennas, and on the expected velocity of the subsurface layers. However, even for the lowest frequency antennas and the highest velocity layers, it is expected that the maximum separation will be no more than a few hundred meters. For simple profiles which require antennas that cannot be attached to the rover, a single astronaut can move both antenna configurations along the profile to acquire the data at each station location.

Figure 4. CMP velocity sounding [2]

Future Work: The objective now is to work with an existing GPR equipment manufacturer that has personnel experienced in lunar research to create an instrument development plan that seeks to cost-effectively modify an existing GPR system or design a new one to work in the extreme lunar environment. This plan also involves determining the best frequencies to use, and conducting terrestrial analog studies with existing and modified GPR equipment.

References: [1] Burger H. R. et al. (2006) *Introduction to Applied Geophysics*, *W. W. Norton & Co., New York*, *New York*, 554 p. [2] Sensors & Software Inc. (2007) *Mississauga, Ontario*, www.sensoft.ca.