THE *STRATA* GROUND PENETRATING RADAR: CONSTRAINING THE NEAR SURFACE PROPERTIES OF SOLAR SYSTEM BODIES.

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Introduction: Ground Penetrating Radar (GPR) is a mature technology widely used in terrestrial applications [1-4] and provides an efficient means for non-intrusively defining subsurface radar properties corresponding to structure (e.g., number and size of ejecta blocks, lava tubes, fractures) and stratigraphy to depths of up to tens of meters [e.g., 5-10] (Fig. 1).

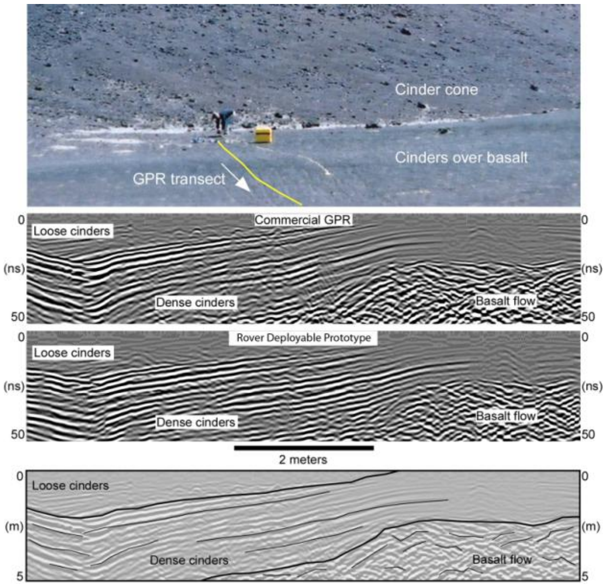

Figure 1. GPR transect across iron-rich volcanic cinders characterized by differing compaction and underlying basalt at Sunset Crater in northern Arizona. Transects completed using a commercial 400 MHz impulse GPR antenna (second from top) and prototype 600 MHz antenna developed for possible future rover deployment on the Moon or Mars (third from top) are shown with interpretation (bottom).

GPR operates by applying a narrow energy pulse through an antenna placed near a surface of interest. The antenna acts as a band-pass filter and emits a single sine wave cycle that is broadcast into the ground at wavelengths ranging from several meters to centimeters (tens of MHz to a few GHz). The longer the incident wavelength, the deeper the expected penetration, but the less ability to resolve closely spaced reflections created by geologic interfaces across changes in physical and electrical properties (e.g., composition). These radar reflections serve as diagnostic "fingerprints" that can help constrain the number and size of buried blocks, thickness and orientation of fractures, and extent of any layers associated with emplacement by different geologic processes (e.g., volcanic vs. impact). GPR penetration is influenced by moisture and composition (e.g., amount of iron or titanium-bearing minerals) and physical parameters (e.g., grain size and porosity). The paucity of liquid water on many solar system bodies, reasonably low loss tangents on the Moon and Mars [e.g. 11-12], results from Mars orbital sounding [e.g. 13-14] and Earth-based radar studies [15, 16] imply GPR should function well on many bodies. Although a GPR has not flown to the planets, the WISDOM GPR was selected to the PASTEUR payload on the ExoMars rover being planned for Mars [17].

The *Strata* GPR: *Strata* is a low-mass (<3 kg), low-power (<7 W peak), and low-volume (~10,000 cc) impulse GPR (Fig. 2) capable of "peering" beneath the surface of solid solar system bodies and providing context for the source, setting, and distribution of detections made by other instruments [18-19]. *Strata* design and development has been funded by multiple NASA programs and the instrument has been field tested and is ready for inclusion in the payload on a future mission to Mars, the Moon, or other solid solar system body.

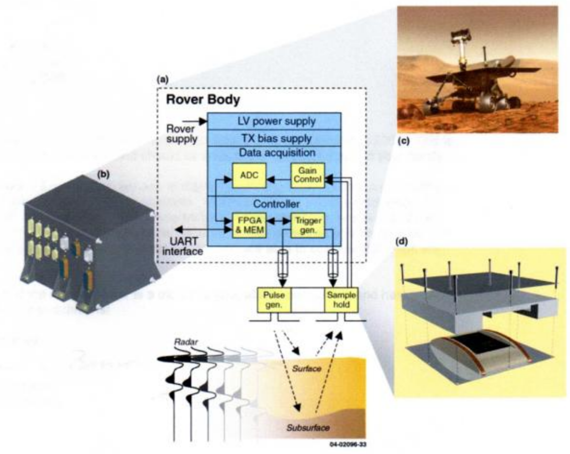

Figure 2. Basic components and deployment scheme for the *Strata* GPR. (a) *STRATA* block diagram with (b) a typical APL instrument digital processor unit (c) a view of the rover, and (d) packaging concept for the antenna assembly that would be mounted on the underside of the rover. DPU = digital processor unit.

Strata (Fig. 2) consists of a low mass and low power digital processor unit and a set of loaded dipole antennas operating at 400 MHz (75-cm wavelength).

With its high dynamic range (~110 dB), *Strata* should be capable of probing 10-15 m into the subsurface of Mars with a nominal resolution of less than 20 cm capable of defining stratigraphy and structure required to characterize geologic settings on solar system bodies.

Strata's antenna can be mounted above the surface on the belly of the rover (protrudes <10 cm) and operates well in high-loss settings characterized by iron-rich substrates (Fig. 1). Positioning the antenna on the rover belly ensures it is not a hazard to rover operations and avoids obstructing the field of view of other instruments. Data requirements are low, with ~0.6 MB/day expected (for 100 meter traverses).

Science With *Strata*: *Strata* can constrain the nature of stratigraphy and surficial deposits along rover traverses and relate them to geologic setting. *Strata* can also help identify potential hazards to rover trafficability and assist in future human exploration of the solar system via helping to define resources/hazards (e.g., distribution of ice deposits and extent/thickness of near-surface fine-grained deposits on Mars).

Strata will define shallow stratigraphy, thereby exposing "virtual" outcrops in the near-surface that can be compared to more scattered, local outcrops and used in evaluating geologic setting. Without knowledge of how data from other rover instruments relate to the overall geologic evolution of a site, samples obtained for analysis can lack the context needed for accurate interpretation. Hence, *Strata* data are essential in targeting samples for other investigations and can help locate the best samples for sample return to Earth.

As an example, much of Mars is mantled by surficial deposits that modify, mask, and impede characterization of underlying deposits and structures diagnostic of high-priority target environments and can cloud interpretation of intriguing geologic settings. A significant portion of the nominal mission of both MER rovers was spent getting information about the nature and origin of any bedrock at the landing sites. This required traverses to locate, characterize, and access rocks that might record a water-lain history. Had *Strata* been in the MER payload, it would have made defining the distribution and character of bedrock more straightforward and helped guide the rovers to samples best suited to meeting mission objectives.

Ongoing terrestrial work with GPR in impact, volcanic, and other settings all contribute to a growing database that can be used to distinguish settings encountered on Mars, the Moon, or other solar system body during future missions. For example, the interpreted distribution of blocks in impact ejecta at Meteor Crater, AZ, using a 400 MHz antenna (the same λ of 75 cm as *Strata*) is 1.5-3 blocks per m^3 in the uppermost 1 m of the subsurface (and 0.5-1 blocks per m^3 in the uppermost two meters), which is close to the *in situ* measured block distribution of 2-3 blocks larger than 0.25-0.30 m per m^3 [20]. This is roughly the detection limit to be expected from the $\lambda/3$ resolution approximation of the radar wavelength and indicates that the 400 MHz GPR is characterizing the block population in ejecta. This population can then be compared to the distribution of blocks and radar stratigraphy mapped in alternate geologic settings or at other impact craters. Collectively, results from terrestrial analog settings will contribute to understanding the likely range in radar properties to depths of 10-15 m on solar system bodies and imply quantitative constraint of subsurface properties and related setting is possible using *Strata*.

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