
Introduction: Ground penetrating radar (GPR) can accurately delineate shallow stratigraphy around a variety of landforms (1-5), thereby limiting the amount of accompanying groundtruth required for interpretation. As a proven instrument in the terrestrial environment, GPR is also being developed for inclusion aboard future Russian missions to Mars (6-7) and is being suggested as a component on future U.S. landers/rovers on Mars (8-12). In anticipation of these missions, GPR effectiveness in a variety of potential Mars analog environments is being explored (e.g., 12). Because much of the Martian surface is mantled by fine-grained unconformable deposits (e.g., 13-19) an understanding of GPR performance in such substrates is crucial. Here, we describe the results of GPR deployment in loess deposits of the Argentine pampas and conclude that the instrument could help place important new constraints on the stratigraphy and origin of possibly analogous fine-grained deposits on Mars.

Field Investigations: A fully digital GSSI GPR was deployed in a continuous mode along transects covering the sandy loessoid deposits of the Pampean Formation (32°45'S; 64°15'W). This work was completed as a part of the ongoing investigation of the Rio Cuarto crater field (20). Local thickness of the loessoid pedocomplex exceeds 15 m and the modal grain size of +4 phi (0.0625 mm) tightly brackets that most readily transported by terrestrial winds (21). GPR transects ranged in length from ~0.03 km to several km's and covered a cumulative distance of ~5-10 km using both 500 MHz and bi-statically configured 100 MHz transducers. Burial of target reflectors and completion of transects along the top of vertical outcrops constrain the dielectric constant of the loess to between 5.5 and 11. Corresponding radar pulse travel times were 9-13 cm/ns, thereby placing the depth of reflectors delineated with the 500 MHz and 100 MHz transducers at depths exceeding 2.5-3.0 m and 3-4 m, respectively. The range in travel times may be caused by degree of pedogenic development, slight variations in grain size, and amount of compaction. Moisture content also influences GPR effectiveness in the immature sediments comprising the loess: near-saturation conditions limit identification of reflectors to ~1 m and less.

Reflectors revealed in the GPR data represented a variety of stratigraphic and pedogenic horizons in the shallow subsurface. Along one river, older fluviually re-worked loess deposits are readily distinguished from younger, overlying and in situ loess despite an insignificant difference in grain size. At least one transect crossing dune-like relief highlights a series of internal reflectors with spacing on the order of 10's of cm's and likely corresponding to structure or bedding. Several isolated, discontinuous hyperbolic reflectors were also identified that apparently mark the location of subsurface blocks and/or pedogenic carbonates, but were not groundtruthed. Most reflectors in the loess are relatively flat-lying and can sometimes be traced for at least several 100's of m's. Such reflectors appear to be due to the occurrence of pedogenic horizons observed in nearby outcrops. One reflector may denote a truncated paleosoil B-horizon of probable hypsithermal age (22). Excavation confirms that other prominent, but less continuous reflectors are created by subtle oxidized zones as thin as 1-2 cm. Ready detection of such a wide range of radar reflectors in the Argentine loess indicates resolution of stratigraphy of comparable scale and complexity should be possible with a GPR in the fine-grained deposits on Mars.

Applications to Mars: Unconformable deposits mantle a significant fraction of the Martian surface including: Arabia, Mesogaeaa, Electris, Tempe, southern Ismenius Lacus, the region northwest of the Isidis basin, around crater Milllochau in Terra Tyrrhena, the interior of the Hellas, Argyre, and Isidis basins, and both the north and south polar regions (13-19, 23). Origin(s) of sediments forming these deposits may relate to eolian redistribution of fine sediments in response to volcanic activity, orbital forcing mechanisms, polar wandering, and/or other processes (e.g., 14, 16, 21). A relatively fine-grained character of the deposits is confirmed by Viking Orbiter thermal inertia measurements (24) and some may possess a relatively low density (e.g., the "stealth" region, 25). Moreover, many of these deposits display at least a crude layering (e.g.,
Electrics) and others (e.g., the polar layered terrains) preserve finer scale and regular, possibly repetitive stratigraphy. Given their widespread occurrence, range in age, and variation in character, understanding the origin of these deposits may hold the key to deconvolution of the history of various geologic processes that have and may continue to shape the Martian surface.

Conclusions: First-order similarities between the morphology of Argentine loess and many of the Martian unconformable deposits suggest GPR would be a useful tool for resolving shallow stratigraphy on Mars. A rover-deployed GPR operating in a continuous mode could cover transects across the deposits measuring several 10's of meters (9-12) and accurately delineate shallow lithologic and/or pedogenic stratigraphy and continuity (e.g., localized and irregular versus regionally uniform). The instrument would be especially effective in desiccated and/or frozen deposits. Moreover, blocky or compacted horizons corresponding to interbedded ejecta or other unconformities might be used to help construct a more regional stratigraphic column. Success of the GPR in loess also implies that the stacking of numerous radar scans obtained in static mode as proposed for the Mars Polar Pathfinder (8) may discern stratigraphy over depths exceeding several 10's of meters. Such information would prove invaluable in identifying any variations in the thickness of individual horizons within the layered terrain sequences and in evaluating their origin(s). More generally, resolution of stratigraphy within the Martian unconformable deposits might allow resolution of their origins when combined with minimal groundtruth provided by shallow cores and/or penetrators. As a result, a GPR may provide important new insight into the changing number and intensities of a range of surface processes (including those controlled by climate) operating on Mars.