Friday, October 17, 2003
Morning Session I
ELECTROMAGNETIC SOUNDING INVESTIGATIONS OF EARTH AND MARS
8:15 a.m. Victoria Room

REVIEW OF THE DAY'S AGENDA

Plaut J. J. * Picardi G. MARSIS Team [INVITED]
Probing the Subsurface of the Martian Polar Regions with MARSIS on Mars Express **[#8131]**

Hamelin M. * Grard R. Berthelier J.-J. Ney R. Trautner R. Simoes F.
Detection and Localization of Mars Sub-Surface Ice by Surface Impedance Measurements from a Rover as Part of the WISDOM/PASTEUR and Other Rover Experiments **[#8006]**

Ori G. G. * Flamini E. Seu R. Marinangeli L.
Testing the SHARAD Experiment of Mars Reconnaissance Orbiter with a Flight Balloon over Polar Regions **[#8058]**

Grant J. A. * Leuschen C. J. Schutz A. E. Rudy J. Williams K. K.
Constraining the Nature and Distribution of Polar Deposits on Mars Using Ground Penetrating Radar **[#8017]**

Holt J. W. * Blankenship D. D. Peters M. E. Kempf S. D. Morse D. L. Williams B. J.
Echo Source Discrimination in Airborne Radar Sounding Data for Mars Analog Studies, Dry Valleys, Antarctica **[#8104]**

GENERAL DISCUSSION

10:15 – 10:30 p.m. BREAK

PROBING THE SUBSURFACE OF THE MARTIAN POLAR REGIONS WITH MARSIS ON MARS EXPRESS.

J. J. Plaut[1], G. Picardi[2], and the MARSIS Team. [1]Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 183-501, 4800 Oak Grove Dr., Pasadena, CA 91109, plaut@jpl.nasa.gov, [2]INFO-COM Department, University of Rome "La Sapienza", Via Eudossiana, 18, 00185 Rome, Italy.

Introduction: The European Space Agency (ESA) is currently conducting a mission to Mars known as Mars Express. The orbiter carries an instrument called the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS). The MARSIS experiment is a joint project between NASA and the Italian Space Agency, and is being carried out by the University of Rome, the Jet Propulsion Laboratory, Alenia Aerospazio, and the University of Iowa. This paper describes the science objectives of the experiment, the instrument characteristics, and applications of the MARSIS investigation to studies of the martian polar regions.

Science Objectives: The primary objective of the MARSIS experiment is to detect, map and characterize subsurface material discontinuities in the upper portions of the crust of Mars. These may include boundaries of liquid water-bearing zones, icy layers, geologic units and geologic structures. Secondary objectives include characterization of the surface topography, roughness and reflectivity, and passive and active ionospheric sounding. Detection of water and ice reservoirs will address many key issues in the hydrologic, geologic, climatic and possible biologic evolution of Mars, including the current and past global inventory of water, mechanisms of transport and storage of water, the role of liquid water and ice in shaping the landscape of Mars, the stability of liquid water and ice at the surface as an indication of climatic conditions, and the implications of the hydrologic history for the evolution of possible Martian ecosystems.

Instrument Description: MARSIS is a multi-frequency, coherent pulse, synthetic aperture radar sounder/altimeter. The instrument features flexibility in frequency selection for adaptation to the Mars environment, and a secondary, receive-only antenna and data channel to minimize the effects of surface "clutter" on subsurface feature detection. The instrument will acquire echo profiles of the subsurface of Mars at a lateral spacing of approximately 5 km and a vertical (depth) resolution of 50-100 m. Four frequency channels will be available for use: 1.8, 3.0, 4.0 and 5.0 MHz. The lower frequency channels, which are likely to penetrate more deeply, will be used during night-side operations, when the ionospheric plasma frequency is lowest. The primary antenna consists of a simple dipole with a total length of 40 m. An impedance matching system is used to improve antenna efficiency across the range of frequencies. The secondary antenna is designed with a null in its pattern at the spacecraft nadir, and will therefore primarily detect echoes from off-nadir surface structure (clutter). On-board digital processing will generate coherently summed echo spectra for both the primary and secondary receive streams, at two frequencies. When data bandwidth is limited, or clutter cancellation is not needed, single frequency and/or single antenna data can be acquired. Post-processing on Earth will include convolution of the primary and secondary antenna profiles for surface clutter cancellation, and compilation of map products showing, for example, the depth to detected interfaces.

Detection of Subsurface Interfaces: A number of factors affect the ability of a radar echo sounder such as MARSIS to unambiguously detect a subsurface interface. A boundary must separate two materials of contrasting real dielectric constant, occur over a lateral length scale at least comparable to the sounder footprint (5 km), and over a vertical length scale smaller than the vertical resolution (50 m). The portion of the crust that lies between the surface and the interface must be sufficiently transmissive to allow a round-trip of the radar signal that is still detectable at the receiver on orbit. Scatterers comparable in scale to the radar wavelength (50-150 m) will disperse energy away from the nadir direction; these scatterers may occur at the surface, within the intervening crust, and at the subsurface interface. Larger-scale roughness (100s of m to km) of the terrain can introduce "clutter" that can mask the echo from a subsurface interface. Such topographic undulations (e.g., crater rims, cliff faces, etc.) may contribute echoes from off-nadir positions that correspond in time-delay to the subsurface region being probed. To minimize the effects of off-nadir scattering, a synthetic aperture approach is applied to isolate echoes in the along-track direction (effectively narrowing the footprint), and the secondary, nadir-null antenna is used to identify (and subsequently remove) off-nadir echoes.

A model of surface and subsurface scattering is developed to evaluate the depths and types of interfaces that may be detected. Crustal rocks are represented by two end-members: a low-loss, moderate dielectric andesite, and a lossier, higher dielectric basalt. The porosity is assumed to be filled by one of three materials: martian atmosphere, water ice or liquid water. Near-surface porosity values of 20% and 50% are used, with an exponential decay with depth. The surface roughness is described by a two-scale model, to take into account wavelength-scale scattering and quasi-specular effects.

Model results show that substantial penetration of the signal can be expected for many reasonable cases of surface roughness, crustal composition and volatile content. The primary "noise" factor above which a subsurface reflection must rise is competing signals from off-nadir. Use of the secondary antenna can lower the off-nadir clutter by 10 dB or more. At the lowest frequency (1.8 MHz), an interface between ice-saturated and water-saturated basaltic crust is detected at depths of 4 km, except for the roughest surface models. In the andesite crust, detection is expected at depths > 5 km. At the higher frequencies, detection depths are less (1-2 km in basalt at 5.0 MHz). An interface between dry rock and ice-saturated rock, which might be expected at moderate depths at low latitudes, is more difficult to detect than an ice-water interface, due to smaller dielectric contrasts between the pore-filling material. However, under favorable conditions of roughness and rock composition, such an interface should be detectable in the upper several kilometers of the crust.

If aquifers occur only at great depth (> 5-10 km) in the martian crust, they may elude detection by MARSIS. However, shallower reservoirs of liquid water, perhaps associated with thermal anomalies or an insulating upper stratigraphy, should detectable. Many other stratigraphic and structural boundaries are expected to be identified by the radar sounding, providing a view into third dimension of the geology of Mars.

Applications in Polar Regions: Data from MARSIS can potentially address several critical issues in Mars polar studies. Of particular interest is the depth and character of the "bed" of the polar layered deposits. If attenuation of the signal by the layered materials is not too great, it may be possible to map the base of the deposits, and detect basal melting zones, should they exist. Detection of pockets of liquid water beneath the layered deposits would be a dramatic result, with implications for possible ecosystems, and regional or global hydrologic systems. Strong discontinuities in dielectric properties may also be detected within the layered deposits, and may be indicative of major climate shifts. It may be possible to measure the thickness and electrical properties of the residual ice (high albedo unit thought to be water ice in the north and CO_2 ice in the south). Recent observations by the 2001 Mars Odyssey gamma and neutron detectors indicate the presence of ice-rich soil in the upper meter of the surface poleward of about 60° latitude. Analysis of the initial reflected pulse in MARSIS profiles should provide an estimate of the bulk dielectric constant of the upper ~50 m, possibly constraining the thickness of the ice-rich zone. If this zone extends to depths of 100s of m, MARSIS profiles may show its base. The thickness of the low-latitude desiccation zone may also be measurable. Properties of other high latitude terrains will be studied, including the thickness of the north polar erg, and possible subsurface stratigraphic contacts among sedimentary and volcanic units in both polar regions. Detection of shallow (< 5 km) aquifers would revolutionize our ideas on the current state of water on Mars, and provide targets for future biologic searches and a possible sustained human presence.

DETECTION AND LOCALIZATION OF MARS SUB-SURFACE ICE BY SURFACE IMPEDANCE MEASUREMENTS FROM A ROVER AS PART OF THE WISDOM/PASTEUR AND OTHER ROVER EXPERIMENTS.

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Introduction: Water and ice on Mars are of great interest for geological, biological and engineering issues. The recent Mars Odyssey missions have shown the presence of water ice in the upper subsurface of Mars in polar regions. At lower latitudes or in particular basins ice should be found at larger depths of several meters. The WISDOM experiment (Water Ice and Subsurface Deposit Observations on Mars) is devoted to the exploration of the subsurface and the search for water and ice in medium latitudes where the subsurface ice could be found at even larger depths. For that purpose it combines a mutual impedance measurement to study the upper layers and a Ground Penetrating Radar that allows reaching larger depths down to a few hundred of meters. In the case of medium-high latitude missions where ice is believed to be at a depth of a few meters, the Mutual and Self Impedance techniques to measure the subsurface permittivity can be used as in the WISDOM project. The instrument is a surface electrode array (7 electrodes) deployed or trailed behind a rover. The multiple combinations between electrodes allow to detect ice embedded in the regolith under an upper layer of dry regolith, and to estimate the depth and ice concentration of the icy layer. It would be possible to follow the ice localization along the track of the rover. That would be very useful information to decide where to drill for a direct access to the ice layer.

Ice identification from permittivity measurements: The Permittivity Probe yields the complex permittivity of the ground over the low frequency range (e.g. 1Hz-10 kHz), by measuring the mutual impedance of two antennas, one operating as a transmitter, and the other one as a receiver. At low frequencies, the rotation of polarized molecules contributes the most significantly to the displacement current. Instruments working in the low frequency domain are therefore well suited to the characterization of the electrical properties of ice mixtures. The dielectric constant of water ice embedded in regolith, at temperatures around 200 K, displays indeed a strong dependence on frequency in the 1-100 Hz range. The Permittivity Probe therefore provides a sensitive measure of the water ice content in the sub-surface.

Subsurface ice detection with multiple electrode arrays: When the electrode array is lying on the surface, far away from the rover, the apparent measured permittivity is the mean of vacuum and ground permittivities. So, a flat system of electrodes is ideal to deduce directly the permittivity from self or mutual impedance measurements. For a single quadrupole, the measurement domain is commensurate with the size of the quadrupole. If the subsurface can be considered as layered horizontally, which is likely the case for subsurface icy layers, a multiple array combining several quadrupole sizes, allows determining the parameters of the layered model, layer permittivities and depths of the interfaces. With the system of 7 electrodes that we propose, it would be possible to estimate at least the characteristics of the upper layer and those of the underlying material where ice is expected. A synthetic model of the subsurface is used for this study.

Instrument design: We discuss the design of the instrument, estimate its main characteristics of size and mass that are relative to the desired depth range of the measurements and we point out the particular points to be addressed in an engineering feasibility study.

Testing the SHARAD experiment of Mars Reconnaissance Orbiter with a flight balloon over polar regions.

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Introduction: SHARAD is a subsurface penetrating radar that will be onboard the Mars Reconnaissance Orbiter (MRO) NASA mission. SHARAD [1] is a facility instrument provided by Agenzia Spaziale Italiana for a NASA mission and the PI is R. Seu (INFOCOM Dept., Univ. Roma "La Sapienza). SHARAD is the direct evolution of MARSIS [2, 3], the subsurface penetrating radar on board the European mission Mars Express. MARSIS has a strong penetration power (a few kilometers) and lower vertical resolution, whereas SHARAD will penetrate only several 100s meters but its data will have high-resolution range. This is achieved with the use of different hardware and different frequencies. One of the goals of MARSIS and SHARAD data is to understand the nature of the signal and compare it with the geological nature of the subsurface.

The two instruments have been not tested yet in flying conditions on Earth. The Agenzia Spaziale Italiana has set up a test campaign in order to evaluate and validate the operation and data of the SHARAD experiment. The Agenzia Spaziale Italiana is planning a test programme in order to evaluate and validate the operation and data of the SHARAD experiment. Possibly, two experiments are envisaged one in Antarctica and the other in the Artic. At present, only one flight will be performed. According to the results of the first test a decision to carry out another test will be taken. The first experiment is scheduled in 2004.

Rationale and operations: Testing a subsurface sounder orbiting radar on Earth is a difficult challenge. The most difficult problem is the presence of interstitial water that, even in small concentration, will strongly attenuate the signal. The consequence is to not have reliable data from most part of the planet. However, the polar areas are good candidates for this kind of test due to the presence of thick cover of ice, as well as the extensive presence of permafrost. A stratospheric balloon flaying at about 35 km above sea level will carry the experiment. The balloon will carry a model of SHARAD with some capability and electronics scaled to the experiment parameters. Both polar regions (the Arctic and Antarctica) are under considerations. The Arctic experiment will be launched from Svalbard where the facility of the Italian base will be used. Simulations of the balloon trajectory show a circular shape with a landing area within 100 km from the launch pad. During the flight the balloon will get data from northern Greenland the Canadian Archipelago and part of northern Siberia and adjoining islands. The experiment will be able to investigate thick ice sheets, permafrost areas, seasonally snow covered zones and sea ice. The Antarctica experiment will flight from the US McMurdo base and the Italian base at Terra Nova Bay will provide the support. Even in this case the trajectory will be circular with the landing near the launch location. In this experiment the balloon will chiefly flight over the thick Antarctic ice sheet.

Preliminary work and data: The selection and timing of the experiment is still under consideration. A preliminary scenario suggests the Arctic flight in summer 2004 with a possible second experiment in winter (Austral summer) 2004.

Fieldwork will be carried out in order to analyse the surface properties along with the gathering of previous data. The ground penetrating radar data already obtained from the surface in the past years by several institutions are of particular interest, because they will be used to control the SHARAD signal when operating on Mars.

Several simulations of the radar signal have been performed in order to model the response of the SHARAD model to the polar environment. Some examples are provided in Figure 1. The ice has been modeled as a layered unit composed of strata of pure ice and ice with silicoclastic detritus. The layer thickness varied according to the simulation experiment ranging from a few tens of cm to a few meters. When a basal layer of melt water is present the bedrock is not recorded. Possible lakes of liquid water will produce, as expected, the same effect with the disappearance of the signal below the water layer.

Conclusion: The experiment with a model of the SHARAD radar on earth will provide useful clues in understanding the signal behaviour and will give some know-how about the geological and glaciological interpretation of the data. This experiment will support the analysis of the SHARAD data and will provide some clues on the use of a similar instrument on the icy satellites.

References: [1] Seu R. et al. (2003) *PSS, in press*. [2] Picardi et al. (1999) *INFOCOM Tech. Rep., n.*007/005/99 [3] Biccari et al. (2003) *PSS., in press.*

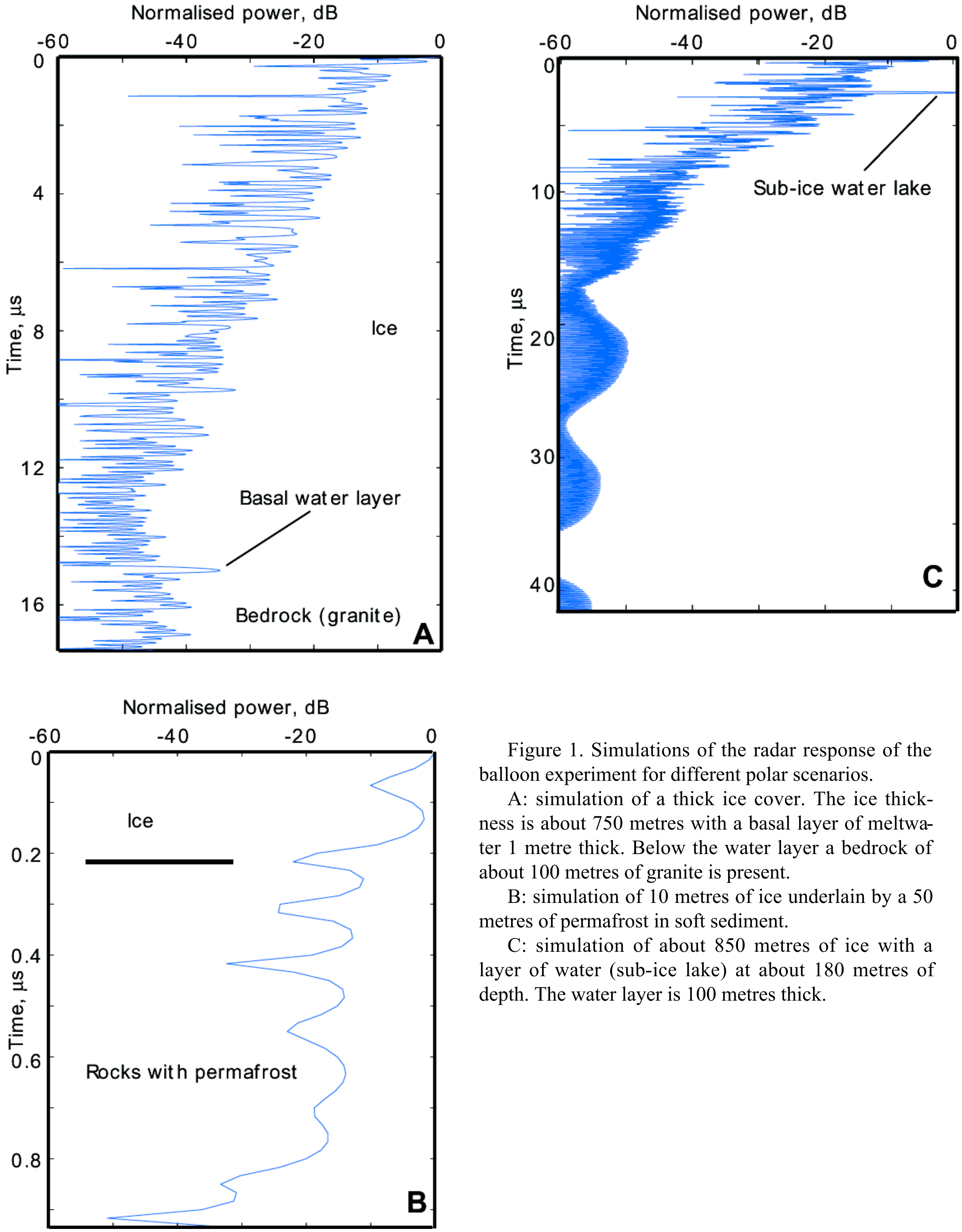

Figure 1. Simulations of the radar response of the balloon experiment for different polar scenarios.

A: simulation of a thick ice cover. The ice thickness is about 750 metres with a basal layer of meltwater 1 metre thick. Below the water layer a bedrock of about 100 metres of granite is present.

B: simulation of 10 metres of ice underlain by a 50 metres of permafrost in soft sediment.

C: simulation of about 850 metres of ice with a layer of water (sub-ice lake) at about 180 metres of depth. The water layer is 100 metres thick.

CONSTRAINING THE NATURE AND DISTRIBUTION OF POLAR DEPOSITS ON MARS USING GROUND PENETRATING RADAR.

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Introduction: Ground Penetrating Radar (GPR) is capable of addressing a variety of geological problems on the Earth and planets. Terrestrial GPR applications have increased dramatically over the past 30 years and the instrument has become ensconced as an efficient means for non-intrusive definition of radar properties to 10's of meters depth [e.g., 1-3]. Given these capabilities, it is likely that measurements made by a rover-deployed GPR on Mars would help achieve a range of Mars Exploration Program goals including those related to understanding the nature and evolution of polar and near-polar deposits and shallow ground ice [4, 5].

For example, a rover-deployed GPR could penetrate eolian drift or snow masking layered or ground ice-rich units and gullies [6-8] to define the stratigraphy of polar layered deposits [9], the distribution of high latitude ground ice [4, 5], or gully settings. Finally, GPR provides the potential to detect rover hazards (e.g., voids or dust-filled cracks) prior to their engagement. Hence, a GPR could make valuable contributions to rover operations in high latitude settings

Developing a Rover-Deployable GPR for Mars: Careful consideration of the various factors influencing radar performance on Mars instills confidence that a GPR can achieve 10-20 m penetration in high latitude settings [2, 3]. Low ambient temperature and a dry near-surface should reduce electrical losses and mitigate difficulties related to the presence of any fines or salts, thereby enabling radar penetration to on the order of 10 times the wavelength [10]. Magnetic losses may be important in substrates with significant iron-bearing minerals [11, 12], but may be less important in fine-grained, ice-rich polar settings.

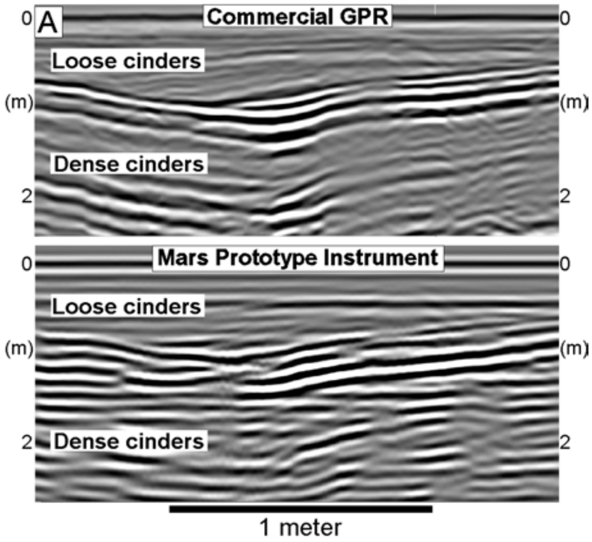
Recognizing that a GPR on Mars could constrain stratigraphy and setting to 10-20 m depth is motivation for development of a rover-deployable impulse GPR. Design of our system has focused on development of prototype antennas in parallel with fabrication of a control unit possessing low mass, volume, peak power, and data requirements of 0.5 kg, 3400 cc, 3 W, and ~0.3 MB/day (for 50 meter traverses), respectively. In order to maximize potential penetration and resolution of a Mars GPR, the capability for both high and low frequency investigations has been incorporated. Present designs include a high frequency (600 MHz) bistatic antenna for near-surface high-resolution sounding and a low frequency (100 MHz) monostatic element for deeper probing. Testing of the prototype antennas in terrestrial analog settings confirms the ability to define near-surface stratigraphy that is critical for accurate interpretation of geologic setting (Fig. 1).

Predicting GPR Performance in Polar Settings: Although GPR has been used in high latitude, ice-rich lcoations on the Earth [3], differences in the materials and settings (e.g. dry-ice, more abundant fines) expected in some polar regions of Mars suggest that prediction of GPR performance warrants additional investigation.

A model based on the Finite-Difference Time-Domain (FDTD) method is being used to constrain likely GPR capabilities on Mars and is capable of modeling the complete instrument configuration including antennas, rover, surface roughness, and rocks. The algorithm is a full-wave simulator, is a direct time-domain implementation of Maxwell's curl equations, and can be used to simulate GPR applications as well as process (reverse-time migration) collected data [13]. Simulations highlight the potential value of investing in such models that may enable diagnostic signatures (such as signal attenuation, frequency content, and phase response) to be identified [14], thereby minimizing potential ambiguities associated with detecting an ice rich deposit from radar reflectivity data alone (Fig. 2). Such simulations can facilitate acquisition of dielectric contrasts (from amplitude and phase information), which (with geologic context) could constrain the local geology and setting in polar settings.

Summary: Inclusion of a rover-deployed GPR on a mission targeted to the polar regions of Mars (e.g., 2009 MSL mission) could provide data critical to achieving mission science objectives. Interpretation of GPR data can lead to accurate definition of geologic setting, define the character of stratigraphy associated with layered-terrains, assist in mapping the distribution of near-surface ice, and define the near-surface properties in the vicinity of gullies. As such, data from a GPR could provide context for other rover instruments, and identify sites/samples for in situ analyses.

References: [1] Ulriksen, C.P.F., 1982, Application of Impulse Radar to Civil Engineering: Ph.D. Thesis, University of Technology, Lund, Sweden, 175p. [2] Grant, J.A., et al. (2003) *J. Geophys. Res*., v. *108*, 10.1029/2002JE001856. [3] Leuschen, C., et al. (2003) *J. Geophys. Res. v. 108*, 10.1029/2002JE001875. [4] Boynton, W. V., et al. (2002), *Science, 297*, 81-85. [5] Feldman, W. C., et al. (2002), *Science, 297*, 75-78, 2002. [6] Christensen, P.R., (1986), J. Geophys. Res., 91, 3533-3545. [7] Ruff, S.W. and Christensen, P.R. (2001) First Landing Site Workshop for the 2003 Mars Exploration Rovers, Ames Research Center, January, 2001. [8] Christensen, P.R., (2003) *Nature, 422*, 45-48. [9] Malin, M. C., and K. S. Edgett (2001), *J. Geophys. Res., 106*, 23,429-23,571. [10] Simpson, R.A., Harmon, et al.(1992), Radar: p. 652-685, in *Mars* (Kieffer, H.H., Jakosky, B.M., Snyder, C.W., and Matthews, M.S., eds.), Univ. Arizona Press, Tucson, AZ, 1498p. [11] Olhoeft, G.R. (1998), Proc. GPR'98, Seventh Int'l Conf. on GPR, University of Kansas, Lawrence, KS, p. 177-182. [12] Paillou, P., et al. (2001), Performances of Ground Penetrating Radars in arid volcanic regions: Consequences for Mars subsurface exploration. [13] Leuschen, C., and R. Plumb, (2001) *IEEE Transactions on Geoscience and Remote Sensing*, *39*, 929-936. [14] Leuschen, C., (2001) *Surface-Penetrating Radar for Mars Exploration*, Ph.D. Dissertation, University of Kansas.



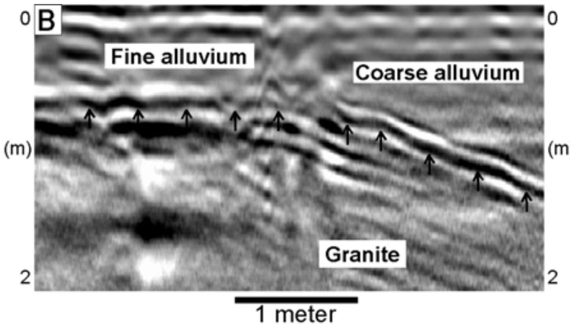


Figure 1. GPR data collected from planetary analog settings using prototype GPR. A) Data from layered volcanic cinders at Sunset Crater, AZ, using commercial 500 MHz antenna (top) and Mars 600 MHz antenna deployed ~15 cm above ground (bottom). B) Data collected using prototype Mars antenna deployed ~15 cm above ground in alluvium over granite bedrock. Arrows show the granite/alluvium contact.

Model: Near-Surface Ice (~2 meters)

top bottom	Lithology	ϕ	*S* ice
0m	atmosphere	100	–
0 m 1.2 m	eolian sediment	50	0
1.2 1.5-2.0	indurated sediment	15	0
1.5-2.0 2.2-2.0	fluvial sediment	30	0
2.2-2.0 6.5-5.5	dirty ice (no rocks)	90	90
6.5-5.5 8.0	non-uniform layered ejecta	10- 20	50

ϕ: porosity (%volume), *S*: saturation

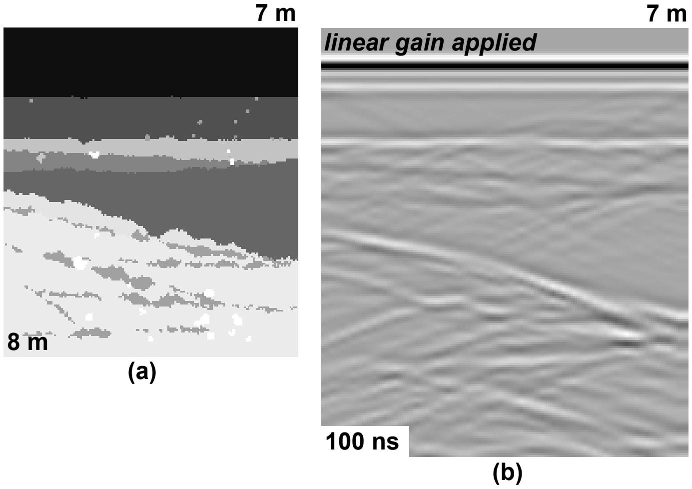


Figure 2 . FDTD simulation of a near-surface ice model. The table describes the stratigraphy, the dielectric distribution is shown in image (a), and the resulting waveforms are in image (b). Numbers in the lower left and upper right of the figure denote simulation depth and distance along the surface, respectively.

ECHO SOURCE DISCRIMINATION IN AIRBORNE RADAR SOUNDING DATA FOR MARS ANALOG STUDIES, DRY VALLEYS, ANTARCTICA.

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Introduction: The recent identification of features on Mars exhibiting morphologies consistent with ice/rock mixtures, near-surface ice bodies and near-surface liquid water [1,2], and the importance of such features to the search for water on Mars, highlights the need for appropriate terrestrial analogs in order to prepare for upcoming radar missions targeting these and other water-related features. Climatic, hydrological, and geological conditions in the McMurdo Dry Valleys of Antarctica are analogous in many ways to those on Mars, and a number of ice-related features in the Dry Valleys may have direct morphologic and compositional counterparts on Mars.

We have collected roughly 1,000 line-km of airborne radar data over permafrost, subsurface ice bodies, rock/ice glaciers, ice-covered saline lakes, and glacial deposits in Taylor and Beacon Valleys. These data are being analyzed in order to develop general radar propagation models of features with direct relevance to Mars.

A crucial first step in the data analysis process is the discrimination of echo sources in the radar data. The goal is to identify all returns from the surface of surrounding topography in order to positively identify subsurface echoes. This process will also be critical for radar data that will be collected in areas of Mars exhibiting significant topography, so that subsurface echoes are identified unambiguously.

Data Acquisition Methods: Using a Twin Otter airborne platform, data were collected in three separate flights during the austral summers of 1999-2000 and 2001-2002 using multiple systems, including a chirped 52.5 – 67.5 MHz coherent radar operating at 750 W and 8 kW peak power (with multiple receivers) and 1 - 2 microsecond pulse width, and a 60 MHz pulsed, incoherent radar operating at 8 kW peak power with 60 ns and 250 ns pulse width. The chirped, coherent data are suitable for the implementation of advanced pulse compression algorithms and SAR focusing.

A laser altimeter (fixed relative to the aircraft frame) was also used during both seasons. Post-processing of the positioning data yields accuracies of ~ 0.10 m for samples at ~ 15 m intervals. Precise positioning was accomplished through the use of two carrier-phase GPS receivers on the aircraft and two at McMurdo Station.

Surface and shallow subsurface properties are being supplied by glacial geomorphologists conducting ground-based studies in Taylor and Beacon Valleys.

Data Acquisition Targets: Flight paths for the Dry Valleys flights in late 2001 are shown in Figure 1. Flights in early 2000 achieved approximately the same coverage, excluding Beacon Valley (due to weather). Flight elevation was nominally 500 m above the surface. Radar and laser altimetry data were collected over the following targets relevant to Mars:

Taylor Glacier: The entire length of Taylor Glacier was surveyed. These profiles extend from Taylor Dome on the polar plateau to the terminus in Taylor Valley

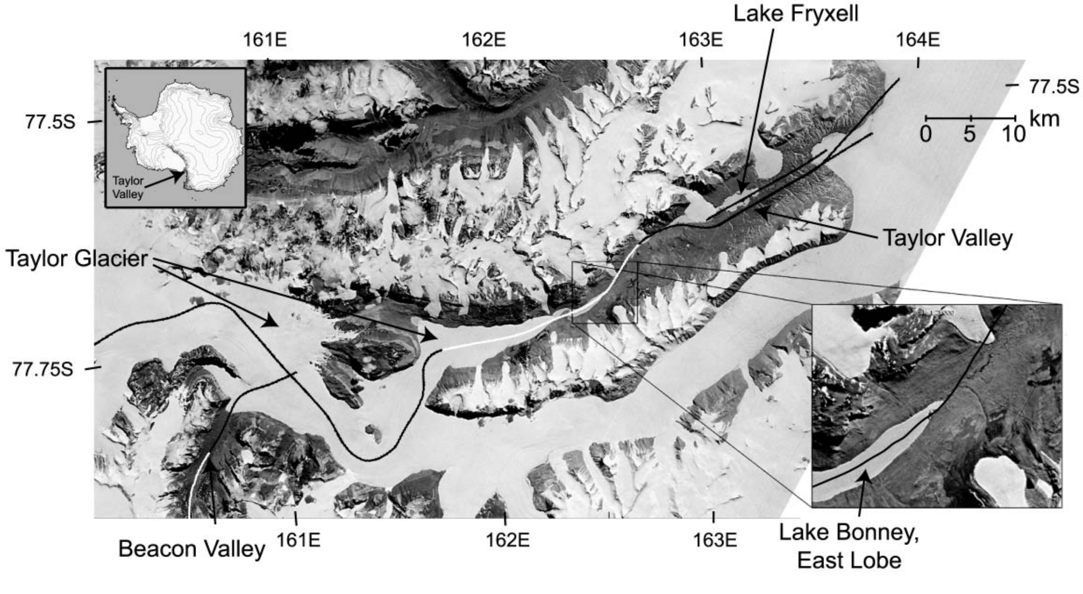

Figure 1. Optical satellite photo of Taylor Valley (center) and Beacon Valley (lower left) within the McMurdo Dry Valleys of Antarctica. UTIG airborne radar profiles (from 2001) are indicated by the solid

black and white alternating lines.

where it is characterized by a high-angle, ice-cored thrust moraine [3]; this profile also includes a lobe that penetrates Beacon Valley. Possible subsurface reflectors in the preliminary data near the terminus appear to be a root of the ice-cored thrust moraine.

Friedman Rock Glacier, upper Beacon Valley: This glacier is 1-2 km wide by 3-4 km long, is heavily debris-covered and is slow moving (max 40 mm/a) [4]. Preliminary data show possible basal reflectors below the glacier where we overflew it.

Debris flows, Taylor Valley: East of Lake Bonney (Fig. 1), a debris flow emanating from the northern wall of Taylor Valley is hypothesized to have occurred in a subaqueous environment [3]. This flow is fairly well defined in the preliminary data (Fig. 2) .

Ancient subsurface ice body, central Beacon Valley: This body is covered by < 1m of glacial drift and hypothesized to be ~ 8 Ma [5].

Permafrost and active layers: In lower Taylor Valley, the Bonney drift includes reworked lake deposits and hummocks thought to be dessicated thrust moraines [3]. Polygonal terrain that we overflew in Beacon Valley is underlain by ice bodies and ice-cemented soil [6].

Lakes Fryxell and Bonney, Taylor Valley: We collected data over both of these ice-covered saline lakes. Permafrost underlies Lake Fryxell [7] and probably Lake Bonney, so we expect a shallow perched water table near the lakes. The reflector underlying the debris flow adjacent to Lake Bonney appears to merge with the lake (Fig. 2).

Data Analysis: The first stage of analysis is the discrimination of subsurface echoes from surface echoes due to surrounding topography. Two techniques are being used in parallel for echo discrimination. Surface returns are being simulated using aircraft position data, the modeled radar antenna pattern, and surface topography from a digital elevation model (DEM) recently acquired by the USGS and NASA in the Dry Valleys with 2-meter postings. These will be compared with the actual data to reveal side echoes.

The second method identifies all echoes in the radar data and maps them into possible correlative surface features to the sides of the aircraft through range estimation. This uses the measured time delay of the echo and known surface topography. We map the echoes onto the DEM (and optical imagery) at the appropriate range in order to identify candidate surface return sources. The two methods should identify all echoes that are not from the subsurface. The comparison of different radar configurations and parallel tracks where they are available will also be utilized to identify the source of any ambiguous echoes.

Once this stage is completed, forward models of the radar properties of these targets will be developed. These can then be applied in a general sense to similar features on Mars, in the context of future radar missions.

Conclusions: Preliminary results of airborne radar sounding in the Dry Valleys of Antarctica indicate penetration of a debris flow, a rock glacier, and massive subsurface ice bodies. Two methods of echo discrimination are being developed in order to confirm apparent subsurface reflectors: (1) forward modeling of echoes using known properties of the radar, antenna pattern and topography, and (2) mapping of radar echoes to the sides of the aircraft to identify features in the topography that could be echo sources.

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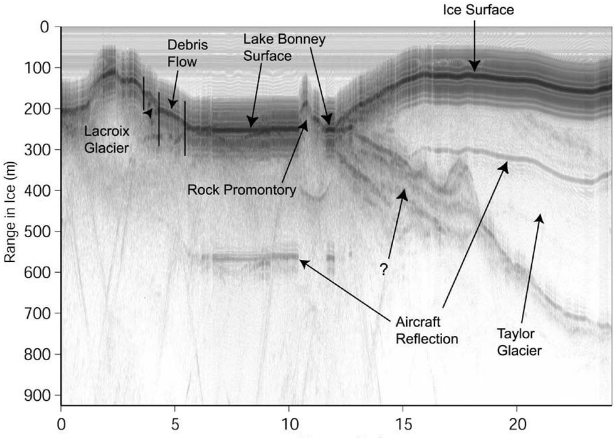

Figure 2. A portion of the radar sounding profile of Taylor Valley (white segment of flight path in center of Figure 1). Up-valley is to the right in this figure. The (?) points to a possible debris-rich layer at the base of Taylor Glacier that may be the source of ice-cored thrust moraines that outcrop at the terminus.