# In Situ Geophysical Exploration by Humans in Mars Analog Environments

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## Introduction

We carried out three geophysical experiments in Mars analog environments in order to better understand the challenges future astronauts will face when conducting similar surveys on Mars or the Moon. The experiments included a passive seismometer deployment and a time-domain electromagnetic survey at the Flashline Mars Arctic Research Station (FMARS) on Devon Island, Canada and a seismic refraction survey in southeastern Utah at the Mars Desert Research Station (MDRS).

FMARS is located on the rim of the 23 Ma Haughton Crater in a polar desert environment. MDRS is located in an area with sedimentary plateaus and canyons of Jurassic to Cretaceous age. Both facilities were built by The Mars Society to help develop key knowledge about human Mars exploration. Crews of six spend 2-4 weeks in the habitats and conduct field research on simulated extravehicular activities (EVAs) wearing mock spacesuits. The work reported here was conducted in July 2009 at FMARS and February 2010 at MDRS.

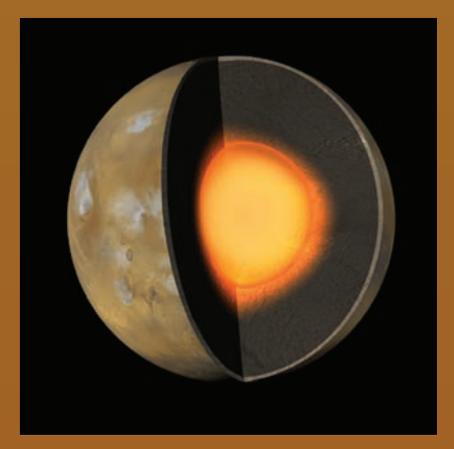
FMARS Expedition 12
2-28 July 2009

The Mars Society

MDRS Expedition 89
23 Jan - 6 Feb 2010

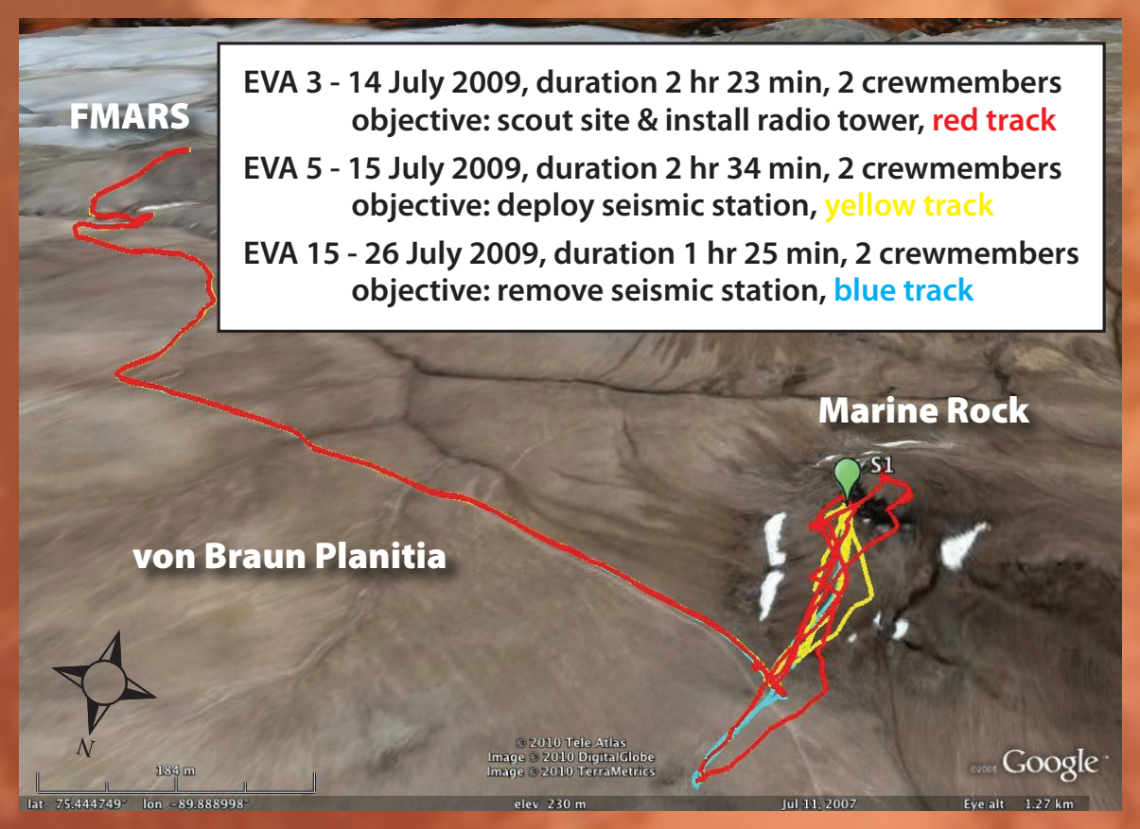
## Passive Seismology

A key to understanding the origin and evolution of planets is characterizing their interior structure, and seismology provides the most complete view of planetary interiors [1]. Deploying a seismic network on Mars is therefore a high priority. Even a single station can provide important information to constrain estimates of seismicity, crustal thickness, mantle models, and core radius [3].



We sucessfully deployed a Nanometrics Trillium Compact semi-broadband seismic station. With its small size (128 mm × 90 mm), low power consumption (160 mW) and easy deployment using a leveling cradle and transport case that doubles as an insulated seismic vault, this instrument is a good analog for those that will be used on Mars [4]. A solar-powered Taurus seismograph recorded the data, which was transmitted to FMARS via 900 MHz ethernet radio. The station operated continously for 12 days at this location and 6 days next the FMARS habitat. Unfortunately, all data was compromised due to a faulty cable.

A) Digging the hole. B) Installing the seismometer. C) Configuring seismograph. D) Installing radio antenna.



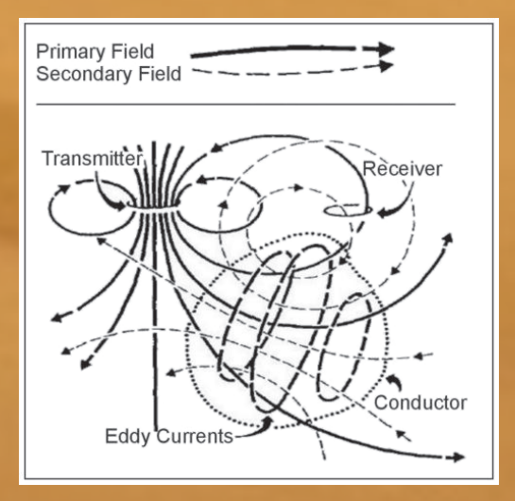
EVA 3 - 14 July 2009, duration 2 hr 23 min, 2 crewmembers
objective: scout site & install radio tower, red track
EVA 5 - 15 July 2009, duration 2 hr 34 min, 2 crewmembers
objective: deploy seismic station, yellow track
EVA 15 - 26 July 2009, duration 1 hr 25 min, 2 crewmembers
objective: remove seismic station, blue track

GPS tracks from the three FMARS seismic EVAs.
(S1 Coordinates: 75.447325°N, 89.902636°W, 260 m)

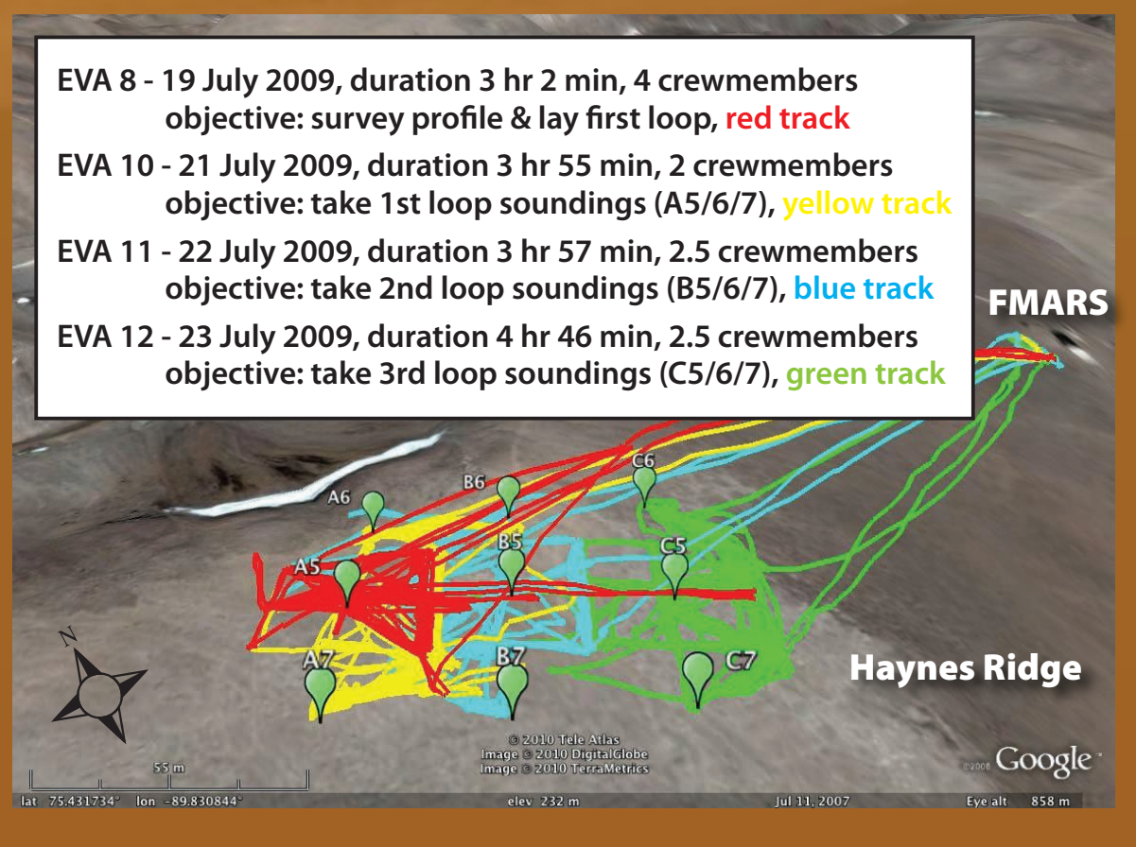
*Equipment generously provided by* Nanometrics SEISMOLOGICAL INSTRUMENTS INC.

## Electromagnetic Sounding

Electromagnetic sounding has been recognized as the most promising exploration method to detect subsurface water on Mars, and efforts are underway to develop hardware for a future lander [5, 6]. The time domain electromagnetic (TDEM) method uses a large transmitter loop to supply a source electromagnetic field. When the current is abruptly turned off, eddy currents in the ground induce magnetic fields that are detected by a smaller receiver loop. This allows for measuring resistivity as a function of depth.

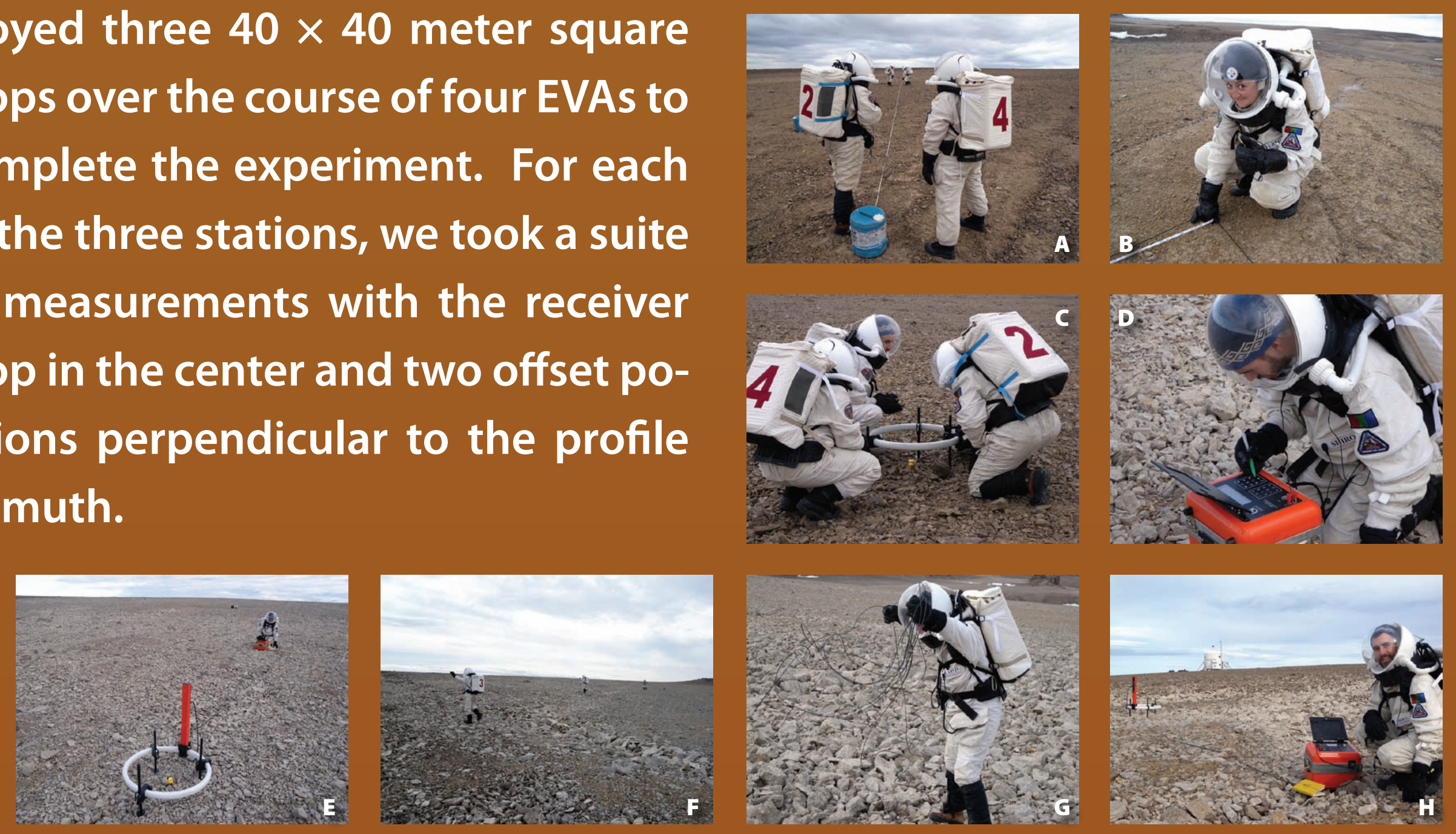


We completed the TDEM survey on the Haynes Ridge 250 meters west of the FMARS habitat using a Geonics TEM47 transmitter and PROTEM receiver. The 120-meter profile was oriented perpendicular to the Haughton Crater rim and was chosen to overlap a 2001 seismic refraction experiment [7]. We deployed three 40 × 40 meter square loops over the course of four EVAs to complete the experiment. For each of the three stations, we took a suite of measurements with the receiver loop in the center and two offset positions perpendicular to the profile azimuth.



EVA 8 - 19 July 2009, duration 3 hr 2 min, 4 crewmembers
objective: survey profile & lay first loop, red track
EVA 10 - 21 July 2009, duration 3 hr 55 min, 2 crewmembers
objective: take 1st loop soundings (A5/6/7), yellow track
EVA 11 - 22 July 2009, duration 3 hr 57 min, 2.5 crewmembers
objective: take 2nd loop soundings (B5/6/7), blue track
EVA 12 - 23 July 2009, duration 4 hr 46 min, 2.5 crewmembers
objective: take 3rd loop soundings (C5/6/7), green track

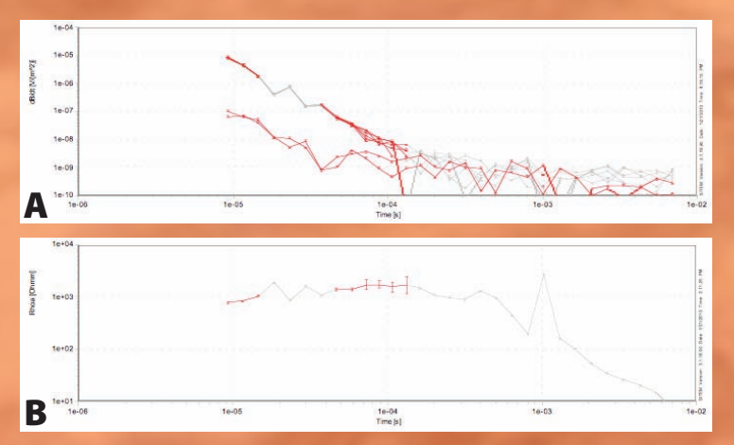
GPS tracks from the four FMARS electromagnetic EVAs. Symbols indicate the locations of the soundinsgs.
(B5 Coordinates: 75.430959°N, 89.833022°W, 234 m)



A) Survey the profile. B) Lay out the square transmitter loop. C) Set up the receiver coil. D) Configure the receiver. E) Take sounding measurements. F) Move the loop. G) Untangle the wires. H) Repeat at each station.

### EM Results

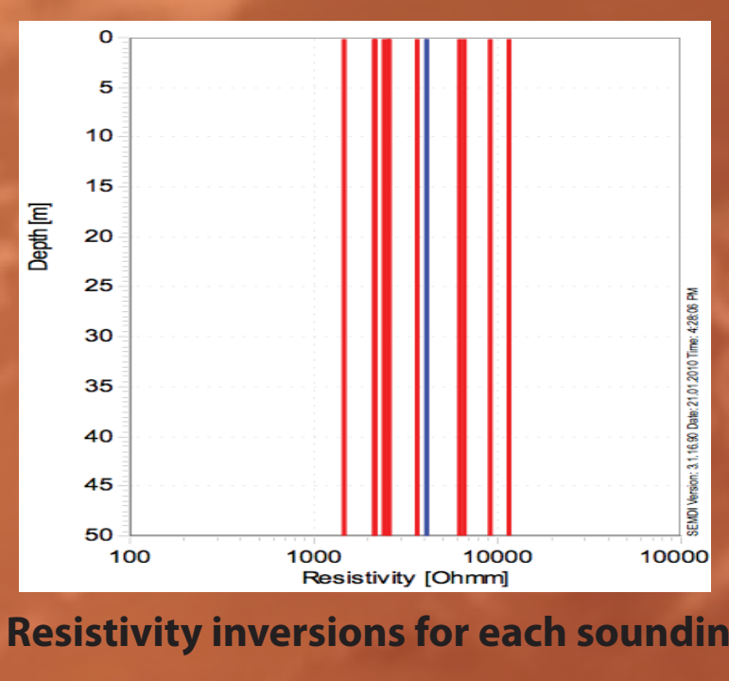
For central- and off-loop soundings, we used a transmitter current of 2 A, and 3.5 A, respectively. The frequency was 30 Hz with a 30 second integration time and gain of 6 or 7. We collected 20 records per component for loop A and 10 for loops B and C.



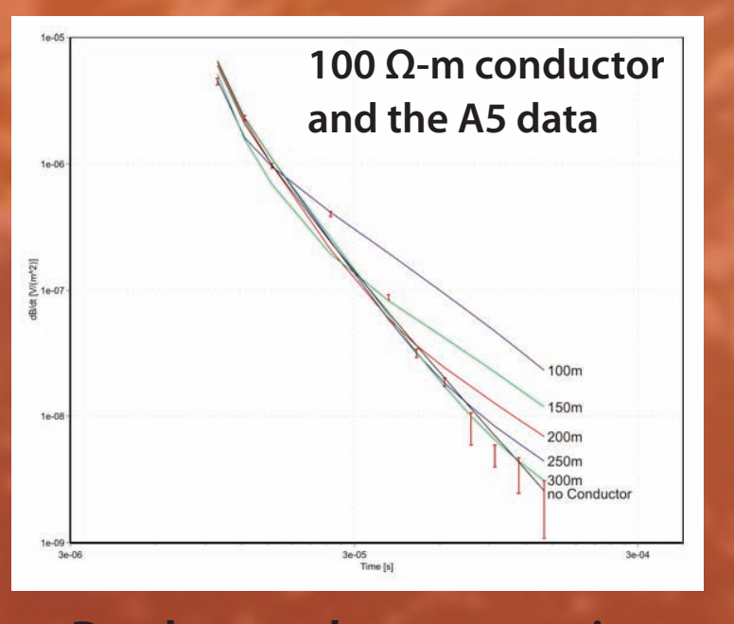
A) Un-normalized dB/dt data from station A5 (center of loop A). Lower two curves are noise sweeps.
B) Average apparent resistivity at station A5.

With only a 40 meter loop and the TEM47 transmitter, we could generate a transmitted moment of 3000 to 6000 A-m². As it turned out, the dolomite rock comprising Haynes Ridge was too resistive for such a small induced moment. The data records were in the background noise by 100 µs.

To have any hope of resolving layering, we needed a loop size at least 100 m and a transmitter with 20 A power. However, using the data above the background noise level, we were able to invert for 1-D profiles of the sub-surface resistivity: 1,000-10,000 Ω-m.



Resistivity inversions for each sounding



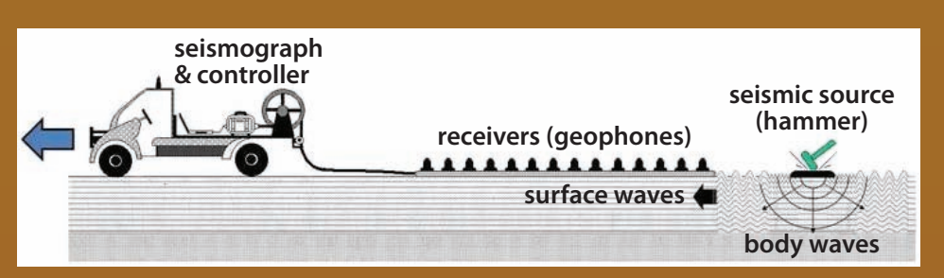
Depth to conductor constraint

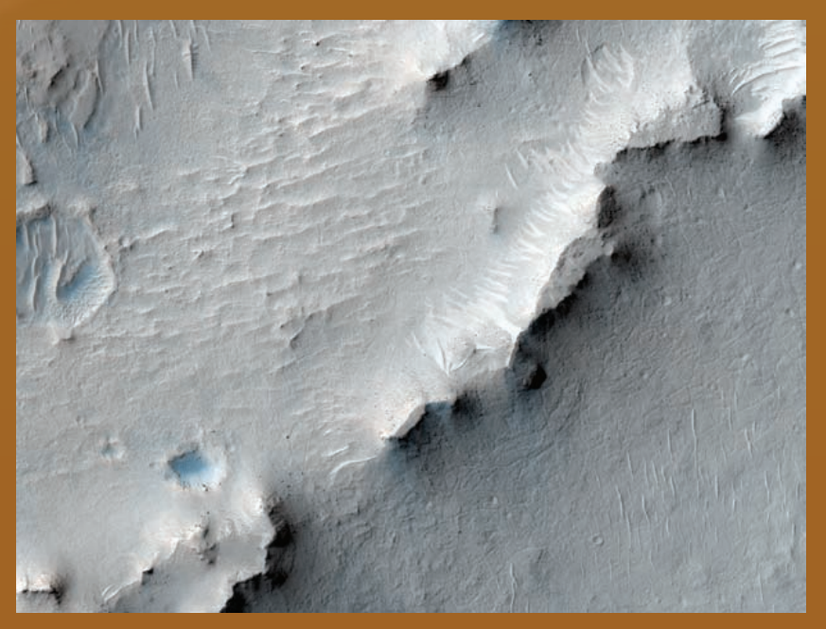
Additionally, we can place an upper bound on the depth to a conductor (like groundwater). The expected resistivity profiles for a 100 Ω-m conductor at different depths match best with a conductor at least 300 m deep.

*Equipment generously provided by* GEONICS LIMITED Leaders in Electromagnetics

## Active Seismology + GPR

Active seismic experiments have long been used to obtain high resolution characterizations of subsurface stratigraphy. Land streamers enable geophysicists to efficiently deploy and move an array of geophones in a less labor-intensive way compared to traditional deployment methods [8]. We tested the feasibility on conducting a seismic refraction profile using a land streamer towed behind a “rover” (ATV).



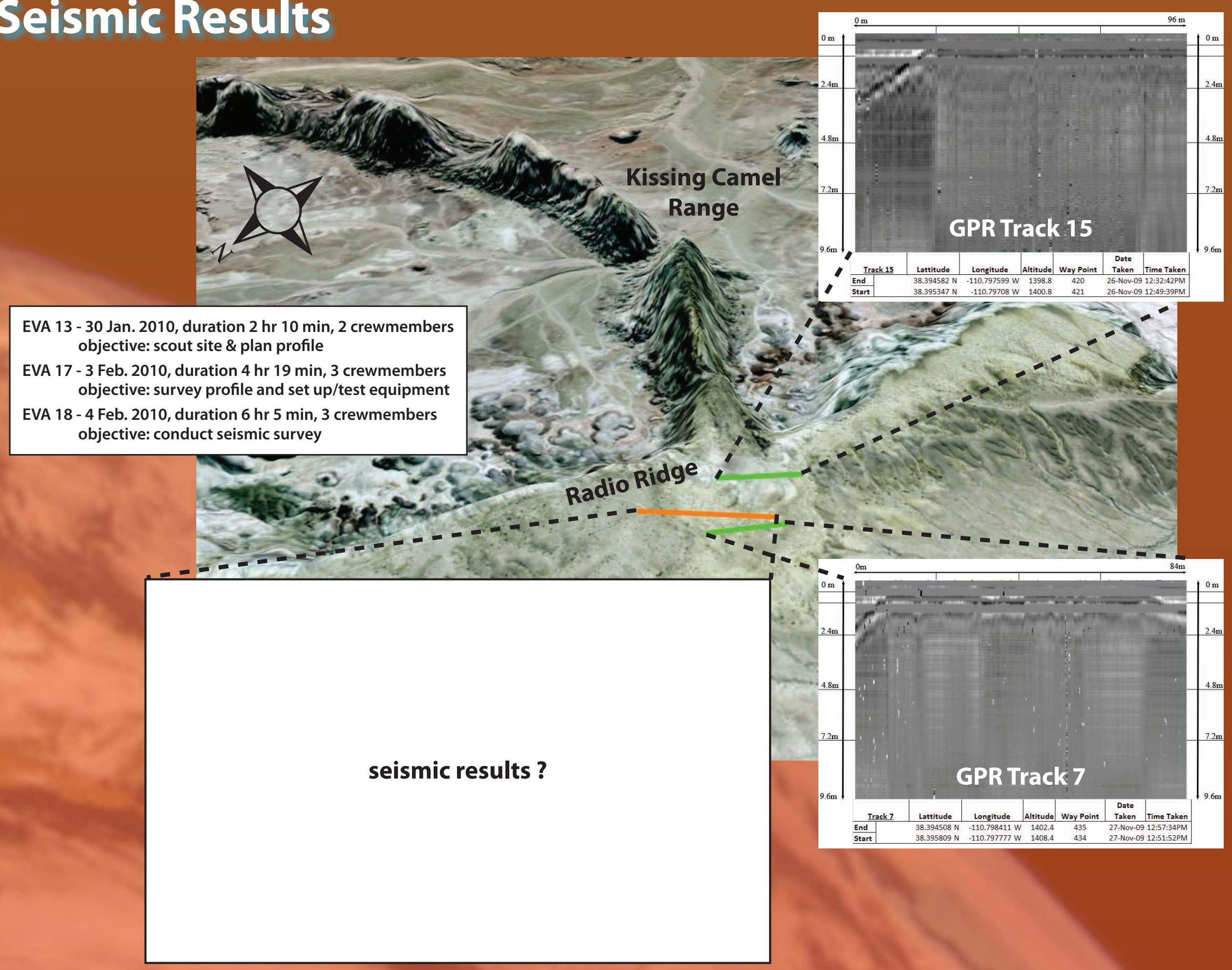


Inverted Channel in Miyamoto Crater
HiRISE image PSP_009985_1770

Ground penetrating radar (GPR) data collected in November 2009 by MDRS Crew 83 [9] discovered a possible buried inverted channel where Kissing Camel Range intersects with Radio Ridge about 2 km south of MDRS (*See poster 2697 in this session.*). Inverted river channels on Earth preserve fossilized life and organic material. They have been seen on Mars too, and one at Miyamoto Crater has been identified as a potential landing site for the Mars Science Laboratory [10]

We conducted the seismic survey there in order to image the feature more completely. Over two EVAs, we successfully took 120 shots of data at 30 locations with 6 geophone spreads covering 109 meters.

### Seismic Results



EVA 13 - 30 Jan. 2010, duration 2 hr 10 min, 2 crewmembers
objective: scout site & plan profile
EVA 17 - 3 Feb. 2010, duration 4 hr 19 min, 3 crewmembers
objective: survey profile and set up/test equipment
EVA 18 - 4 Feb. 2010, duration 6 hr 5 min, 3 crewmembers
objective: conduct seismic survey

| Track 15 | Lattitude | Longitude | Altitude | Way Point | Date Taken | Time Taken |
|---|---|---|---|---|---|---|
| End | 38.394582 N | -110.797599 W | 1398.8 | 420 | 26-Nov-09 | 12:32:42PM |
| Start | 38.395347 N | -110.79708 W | 1400.8 | 421 | 26-Nov-09 | 12:49:39PM |

| Track 7 | Lattitude | Longitude | Altitude | Way Point | Date Taken | Time Taken |
|---|---|---|---|---|---|---|
| End | 38.394508 N | -110.798411 W | 1402.4 | 435 | 27-Nov-09 | 12:57:34PM |
| Start | 38.395809 N | -110.797777 W | 1408.4 | 434 | 27-Nov-09 | 12:51:52PM |

*Equipment generously provided by* Exploration Instruments

## References & Acknowledgements

We would like to thank the staff and volunteers at The Mars Society for facilitating these expeditions. Gene Traverse of Nanometrics provided support for the passive seismic deployment. Rob Harris of Geonics, Paul Bedrosian of the USGS, and David Stillman of SwRI provided invaluable sup-port to the TDEM experiment. Thanks also to Dennis Mills of Exploration Instruments for his help with the land streamer deployment. Conversations with Bob Grimm of SwRI and Rob Stewart of University of Houston were also instrumental in helping to plan these experiments.

**In Situ Geophysical Exploration by Humans in Mars Analog Environments.** B. Shiro[1] and K. Ferrone[2], [1]Department of Space Studies, University of North Dakota, Grand Forks, ND 58202 (brian.shiro@gmail.com) , [2]Sasakawa International Center for Space Architecture, University of Houston, Houston, TX 77204 (kristine.ferrone@gmail.com).

**Introduction:** We carried out three geophysical experiments in Mars analog environments in order to better understand the challenges future astronauts will face when conducting similar surveys on Mars or the Moon. The experiments included a passive seismometer deployment and a time domain electromagnetic survey on Devon Island, Canada and an active seismic refraction survey in southeastern Utah. The poster will highlight preliminary results and lessons learned from a human factors standpoint.

**FMARS:** The Flashline Mars Arctic Research Station (FMARS) is a facility built by The Mars Society in 2000 to help develop key knowledge about Mars exploration and to inspire the public to this cause. It is located on Devon Island in Nunavut Territory, Canada about 1600 km from the North Pole at 75°25' N, 89°49'W. The remote outpost is located on the western rim of the 23 Ma Haughton Crater in a polar desert environment geologically and biologically similar to Mars.

In July 2009, the twelfth crew inhabited the remote outpost for a month-long simulated Mars expedition. We lived in the small habitat, observed strict communication delays with "Earth" and conducted daily EVAs wearing spacesuits to learn how humans might live and work on Mars. Two of the research experiments carried out in 2009 were a passive seismic and time domain electromagnetic survey. More information about the mission is available on the crew website at http://fmars2009.org/.

*Passive Seismic Deployment.* A key to understanding the origin and evolution of planets is characterizing their interior structure, and seismology provides the most complete view of planetary interiors [1]. Analysis of data collected by the Apollo Seismic Experiment has provided most of our knowledge about the interior structure of the Moon, but compromises made in the Viking Seismic Experiment rendered its data unusable [2]. Deploying a seismic network on Mars is therefore a high priority. Even a single station can provide important information to constrain estimates of seismicity, crustal thickness, mantle models, and core radius [3].

We deployed a Nanometrics Trillium Compact seismometer 3 km west of FMARS near an outcrop known as Marine Rock. This instrument incorporates a symmetric triaxial force feedback sensor with a flat velocity response from 120 seconds to 100 Hz. With its small size (128 mm × 90 mm), extremely low power consumption (160 mW) and easy deployment using a leveling cradle and transport case that doubles as an insulated seismic vault, this instrument is a good analog for those that will likely be deployed on the Moon or Mars [4]. We used a solar-powered Taurus seismograph to power the station and record the data and an Ethernet radio to transmit the data back to FMARS in real time.

**Figure 1:** Brian Shiro and Christy Garvin test the seismometer (upper left) before burying it.

*Time Domain Electromagnetic Survey.* Electromagnetic sounding has been recognized as the most promising exploration method to detect subsurface water on Mars, and efforts are underway to develop hardware for a future lander [5, 6]. The time domain electromagnetic (TDEM) method uses a large transmitter loop to supply a source electromagnetic field. When the current is abruptly turned off, eddy currents in the ground induce magnetic fields that are detected by a smaller receiver loop. This allows for measuring ground conductivity as function of depth.

We completed the TDEM survey on the Haynes Ridge next to the FMARS habitat using a TEM47 transmitter and PROTEM receiver on loan from Geonics Limited. The 120-meter profile was oriented perpendicular to the Haughton Crater rim and was chosen to overlap a 2001 seismic refraction experiment [7]. We deployed three 40 × 40 meter square loops over the course of four EVAs to complete the experiment. For each of the three stations, we took a suite of measurements with the receiver loop in the center and two offset positions perpendicular to the profile azimuth.

**Figure 2:** Brian Shiro takes some TDEM soundings with the FMARS habitat in the background.

**MDRS:** The Mars Desert Research Station (MDRS) is a facility very similar to FMARS that was built by The Mars Society in 2002 in the remote Utah desert near the small town of Hanksville at 38°24' N, 110°47'W. The sedimentary canyon formations and sparse biology of the area provide a good analog Mars environment for conducting simulated EVA operations.

From 23 January through 6 February 2010, the 89th crew inhabited the MDRS for a two-week mission. With living and working arrangements much like FMARS, we carried out a number of experiments on simulated EVAs, including an active seismic survey. More information about the mission is available on the crew website at http://wkiri.com/mdrs_crew89/.

*Active Seismic Survey.* Active seismic experiments have long been used to obtain high resolution characterizations of subsurface stratigraphy. Although past teams have deployed geophones wearing spacesuits, none have yet worked with the newer land streamer technology [8]. Land streamers are similar to marine streamers that allow for easy towing of hydrophones behind boats for marine seismic surveys. They enable geophysicists to efficiently deploy and move an array of geophones in a less labor-intensive way compared to traditional deployment methods.

We obtained a 2-D profile of the subsurface near MDRS using a Geostuff Land Streamer with twenty-four 4.5 Hz geophones spaced 1.5 meters apart. We towed the streamer along the ground using one of our ATV Mars rovers. A sledgehammer striking a metal plate served as the seismic source.

**Conclusion:** In general, we learned that instrument user interfaces need to be as simple as possible to maximize astronaut efficiency during EVAs. In particular, buttons should be large and easily depressed, and screens should be easily readable even through a spacesuit helmet. Ideally, there would be some way to interface the control system to a heads up display in the spacesuit helmet itself. Menu systems for configuring equipment should be as minimal as possible and should preferably be pre-configurable so that the astronaut in the field only needs to position the instrument and turn it on. Laying out a large loop by hand for TDEM work is probably not a practical or efficient use of astronaut time, so automating that process with robotics or by making the loop mobile on a rover would be better strategies. Land streamers are much easier to deploy than individually planted geophones, but they are heavy and bulky to handle. Wireless geophones could be deployed in a more versatile sensor web framework while also saving valuable mass and volume.

**References:** [1] Lognonné, P. (2005) *An. Rev. Earth Planet. Sci., 33,* 571-604. [2] Anderson, D. *et al.* (1976) *Science, 194,* 1318-1321. [3] Lognonné, P. and B. Banerdt (2003) *6th Int'l Conf. Mars,* Abstract #3225. [4] Lognonné, P. (2000) *Planet. Space Sci., 48,* 1289-1302. [5] Grimm, R. (2002) *J. Geophys. Res., 107,* doi:10.1029/2001JE001504. [6] Grimm, R. *et al.* (2009) *Planet. Space Sci., 57,* 1268-1281. [7] Pletser, V. *et al.* (2009) *Acta Astronautica, 64,* 457-466. [8] van der Veen, M. *et al.* (2001) *Geophysics, 66,* 482-500.

**Acknowledgements:** We would like to thank the staff and volunteers at The Mars Society for facilitating this important Mars analog research. Gene Traverse of Nanometrics provided support for the passive seismic deployment. Rob Harris of Geonics, Paul Bedrosian of the USGS, and David Stillman of SwRI provided invaluable support to the TDEM experiment. Thanks also to Dennis Mills of Exploration Instruments for his help with the land streamer deployment. Conversations with Bob Grimm of SwRI and Rob Stewart of University of Houston were also instrumental in helping to plan these experiments.