THE MARS UNDERGROUND MOLE (MUM): A SUBSURFACE PENETRATION DEVICE WITH IN SITU INFRARED REFLECTANCE AND RAMAN SPECTROSCOPIC SENSING CAPABILITY.

C.R. Stoker[1], L. Richter[2], W.H. Smith[3], L.G. Lemke[4], P. Hammer[5], J.B. Dalton[6] B. Glass[7] and A. Zent[8]. [1]NASA Ames Research Center, Code SST, Moffett Field, CA 94035, carol.r.stoker@nasa.gov; [2]DLR Institute fur Raumssimulation, D-51147 Koln, Germany lutz.richter@dlr.de; [3]Medeco Inc.89 Arundel Place, Clayton, MO 63105, whsmith@levee.wustl.edu; [4]NASA Ames Research Center, Code SF, Moffett Field, CA 94035 llemke@mail.arc.nasa.gov; [5]NASA Ames Research Center, Code SG, Moffett Field, CA 94035, phammer@gaia.arc.nasa.gov; [6]NASA Ames Research Center, Code SST, Moffett Field, CA 94035, dalton@mail.arc.nasa.gov; [7]NASA Ames Research Center, Code IC, Moffett Field, CA 94035, brian.j.glass@nasa.gov; [8]NASA Ames Research Center, Code SST, Moffett Field, CA 94035, azent@mail.arc.nasa.gov

Introduction and Background: Searching for evidence of life on Mars will probably require access to the subsurface. The Martian surface is bathed in ultraviolet radiation which decomposes organic compounds [1], destroying possible evidence for life. Also, experiments performed by the Viking Landers imply the presence of several strongly oxidizing compounds at the Martian surface that may also play a role in destroying organic compounds near the surface[2]. While liquid water is unstable on the Martian surface, and ice is unstable at the surface at low latitudes, recent results from the Mars Odyssey Gamma Ray Spectrometer experiment [3] indicate that water ice is widely distributed near the surface under a thin cover of dry soil. Organic compounds created by an ancient Martian biosphere might be preserved in such ice-rich layers. Furthermore, accessing the subsurface provides a way to identify unique stratigraphy such as small-scale layering associated with lacustrine sediments. Subsurface access might also provide new insights into the Mars climate record that may be preserved in the Polar Layered Deposits and other sediments. Recognizing the importance of accessing the subsurface of Mars to the future scientific exploration of the planet, the Mars Surveyor 2007 Science Definition Team called for drilling beneath the surface soils[4]. Subsurface measurements are also cited as high priority in by MEPAG [5].

Figure 1. PLUTO mole demonstrated on Mt. Etna in Sept. 2002. The inset lower right shows the sampling device.

The European Space Agency has incorporated a small automated burrowing device called a subsurface penetrometer or “Mole” onto the Beagle 2 lander planned for 2003 launch [6]. This device, called the Planetary Underground Tool (PLUTO), is a pointed slender cylinder 2 cm wide and 28 cm long equipped with a small sampling device at the pointed end that collects samples and brings them to the surface for analysis. Figure 1 shows the PLUTO mole. Drawing on the PLUTO design, we are developing a larger Mole carrying sensors for identifying mineralogy, organic compounds, and water.

The Mars Underground Mole: The Mars Underground Mole was recently selected for development by the Mars Instrument Development Program (MIDP). The Mole advances into soil by way of an internal sliding hammer system driven by a small electric motor. Part of the energy released by the spring-loaded hammer with each shock is transferred to the Mole casing and from there to the soil, resulting in penetration by displacing and compressing the surrounding soil. A backwards-directed impulse as a reaction to each forward shock is transferred via a suppressor mass against a second weaker spring allowing forward motion without requiring reactive forces provided by the lander. The Mole tip can be opened to collect soil samples. The Mole casing is tethered to a supporting mechanism that supplies power. Components supporting the Mole on the surface include a launch tube, tether reel and winch for pulling in tether, in addition to the tether itself.

In addition to its use as a mechanism for collecting subsurface samples, a Mole is a useful device for carrying an instrument payload underground to make *in situ* measurements. However, due to the size limitations on an on-Mole instrument compartment, and the availability of a tether, it makes sense to put instrument electronics on the surface. With funding from MIDP, we are developing an instrument package to be integrated with a Mole. The centerpiece of this package is the Dual Spectral Sensor (DSS), a Short Wave Infrared (SWIR) Spectrometer with sensitivity from 0.7 to 2.5 micrometers combined with a Raman Spectrometer. The DSS is capable of sensing a wide range of minerals relevant to Mars Surveyor Program objectives of tracing the history of water on Mars including hydrated minerals, clays, carbonates, sulfates, and ice. Additionally, Raman spectroscopy is effective for detecting organics. The DSS design is based on the Digital Array Scanning Interferometer technology [7], a type of Fourrier transform interferometer which uses fixed element prisms and thus is highly rugged compared to a Michaelson interferometer. The instrument mass (with reserves) is 1 kg. Table 1 shows the performance characteristics of the DSS. In order to minimize the diameter of the Mole, the design calls for the detector and instrument electronics to remain on the surface. Light is transmitted to them from an optical port located in the Mole via fiber optics incorporated into the tether. While not part of our MIDP funded development, other instruments for analysis of soil samples without retrieving them to the surface can plausibly be incorporated into a Mole. For example, a small microscopic camera could be housed in the Mole body, viewing soil through an optical port, thus allowing particle size and shape to also be measured.

Table 1. *DSS Instrument Specifications*

Spectral Resolution	10 nm at 1000 nm
Resolving Power	$\delta\lambda/\lambda$ =200
Detection limits:	
Water/ice/hydrated minerals	< 1 %
Clays	3-5 %
Iron Oxides	<1 %
Carbonates	1 %
Organics	
• Amines and Amino Acids	3-5 %
• C-H carbon compounds	1-3 %

The MUM is designed to achieve a maximum depth of penetration of 5 m in Mars regolith. It can be repeatedly deployed and retrieved, with the number of penetrations limited chiefly by wear on the hammering mechanism. For an average Mars soil model, we expect that MUM can sample to 1 m depth in at least ten locations. The ability to perform repeated sampling, combined with the low mass and power requirements, means that the Mole could be incorporated into a rover mission as well as used on a stationary platform as in the case of the Beagle 2. The MUM is retrieved to the surface via a tether retrieval mechanism (pulling the Mole up) while also reversing the direction of hammering. The MUM can also be deployed horizontally to obtain samples from beneath a rock. Figure 2 shows the two possible configurations for deploying the MUM. Table 1 shows the characteristics of the MUM as compared to those of the Beagle 2 PLUTO system.

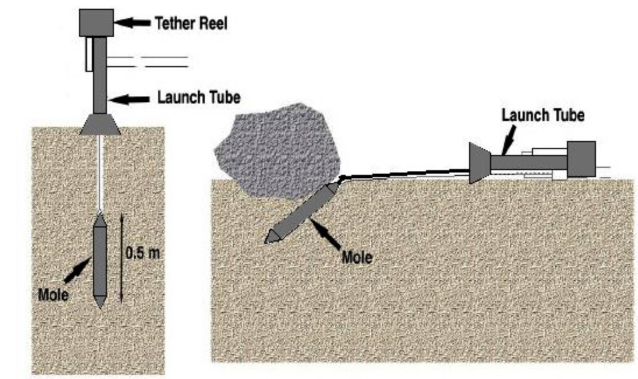

Figure 2. The MUM Mole, launch tube, and tether reel are schematically illustrated. The Mole can extract samples from a vertical hole (left) or from under a rock when launched horizontally on the surface (right).

Table 2.

MOLE PERFORMANCE		
Parameter	**MUM**	**PLUTO**
Mass (Tether, Tether Reel, Launch Tube) (gm)	2500	510
Mass (mole) (gm)	1000	350
Length (cm)	50	28
Diameter (cm)	4 (TBC)	2
Peak Power (W)	10	3
Theoretical Penetration Depth Limit* (m)	5	5
Baseline Penetration Depth (m)	5	2.6
Performance Floor Penetration Depth (m)	2	1.5
Seconds per Cycle	5	5
Duration to Performance Floor Depth (hrs)	1.3	2
Retraction Mechanism (RM)	Surface winch, reverse hammering	Surface winch, reverse hammering
RM Force Capability (N)	300 (TBC)	80
Target Sample Size (cm3)	5	0.2
Number of Holes (1 m deep)	10	3-5
Fault Recovery System	Pyro guillotine, inclinometer, reverse hammering	reverse hammering
Sensors	DSS, inclinometer, temperature, paid out length of tether (in RM)	Temperature, paid out length of tether (in RM)

* Mars Environment

In a Mars mission, MUM could address numerous high priority science objectives. For example, it could be used to determine the mineralogy, stratigraphy, and search for evidence of subsurface organic material in a Martian paleolake bed, Polar Layered Deposit, or other regions of interest; conduct *in situ* analysis of minerals below the UV-irradiated surface layer; help characterize the state and distribution of water in the regolith, determine the presence of ice lenses, and characterize correlations between mineralogy and H_2O abundance; characterize layering in dune deposits; or investigate the nature of indurated deposits. An important advantage of a Mole over more conventional drilling is that it produces a minimal thermal disturbance and thus could allow measurements of undisturbed volatile abundance.

We plan to test the MUM package in a variety of environments. Some tests will be performed in a specially-constructed chamber filled with materials of plausible Martian composition and stratigraphy. Other tests will be performed in realistic Mars analog environments such as dry lake beds and permafrost regions. The purpose of our testing will be to bring the Mole and instrument package to TRL 6 by 2005 to be ready for flight on the 2009 MSL mission.

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