THE PLANETARY UNDERGROUND TOOL (PLUTO) EXPERIMENT ON THE BEAGLE 2 MARS LANDER.

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Introduction: The payload of the Beagle 2 Mars lander of ESA's Mars Express mission includes a regolith-penetrating, tethered "Mole" intended for acquisition of several subsurface soil samples from depths between about 10 cm and approximately 1.5 m. These samples will then be analysed by the Gas Analysis Package (GAP) instrument on the lander, primarily with regard to isotopic composition and organic molecules [1]. In addition, a share of each sample can be deposited onto the lander structure to be investigated with instruments mounted on the lander's PAW instrument carrier, such as the Mossbauer and X-ray fluorescence spectrometers and the optical microscope. After giving a brief overview of the experiment design, this paper focuses on the various science objectives addressed by the Beagle 2 Mole system, also referred to as the PLanetary Underground TOol (PLUTO). Apart from its capability to make subsurface regolith samples available to lander-based experiments for the first time on a Mars landing mission, PLUTO will be capable of performing scientific measurements of its own which utilize the Mole's soil penetration process and its temporary residence within the regolith.

PLUTO Overview: The PLUTO instrument on the Beagle 2 Mars lander, scheduled to arrive at Mars on December 25 this year, has at its core an electromechanical "Mole" that is able to penetrate into soil-like materials by way of soil displacement through an internal hammering mechanism that transfers periodic force strokes from the Mole to its outside environment [2]. In the presence of friction with the surrounding material, a self-penetration without requiring reactive forces from the lander is possible, allowing to link the Mole to lander-based elements through a tether which also serves as the primary means of retrieving the device. Hammer mechanism sizing allows to advance to depths of about 1.5 m in Viking-type "blocky" soil with an assumed hyperbolic increase of bulk density and shear strength with depth, within about 2 h of continuous hammering while at Martian gravity, with average electrical power uptake of roughly 3 W. A sampling mechanism in the front of the Mole can be commanded to open to capture a soil sample between about 5 mm^3 and 200 mm^3, depending on sampler operating scheme. A winch mechanism residing above the surface will allow to reel the Mole back inside a "holster"-like guiding tube – supported by Mole backwards hammering - which is maneuvered by the lander mechanical arm to allow sample discharge to either the sample inlet of the Gas Analysis Package (GAP) instrument or onto the lander deck. In all, three subsurface sample acquisitions from the Martian regolith are planned during the course of the mission within reach of the lander arm, from various depths not exceeding about 2 m. Overall mass of PLUTO including winch mechanism and tether is 860 g at a stowed length of 365 mm.

Fig. 1: Beagle 2 in deployed configuration on surface of Mars (artist's impression).

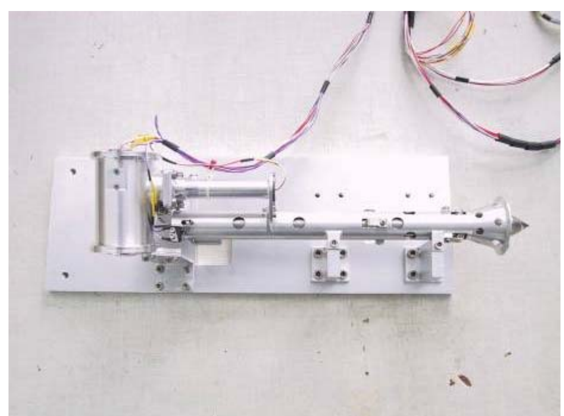

Fig. 2: PLUTO Qualification Model (with winch reel mechanism and guiding tube).

Subsurface Sample Analyses: The lander-based GAP instrument, using pyrolysis and stepped combustion processes, aims at studying the retrieved subsurface soil samples in light of a search for organic molecules either imported by carbonaceous meteorites or perhaps produced on Mars by non-biological or even biological processes [3]. Access to subsurface soil for this type of investigation is considered essential to account for Mars soil oxidant hypotheses as well as decomposition processes driven by solar UV alone [4], [5]. Moreover, analyses of subsurface soil samples by the Beagle 2 Mossbauer spectrometer after sample deposition on the lander structure offer the potential to directly investigate oxidation state as a function of sample provenance (depth). GAP additionally will be able to measure water released from samples during pyrolysis, allowing to differentiate between chemically bound and adsorbed water [6] while delivering ground truth for the Mars Odyssey GRS suite measurements of soil hydrogen abundance.

Soil Mechanics: The PLUTO Mole will allow mechanical properties of the regolith to be inferred from the way it proceeds into the Martian soil. Using a Mole soil penetration theory calibrated by ground-based experiments, regolith bulk density, cohesion, and internal friction angle can be constrained as a function of depth using the Mole penetration path (and retrieval path) vs. time which is measured by a sensor indicating the amount of tether extracted by the Mole. The obtained depth profiles of these quantities should provide insight into the depositional history and stratigraphy of the regolith at the site by uncovering any layering of soils with different mechanical properties being indicative of the upper horizons of the local geological sequence. It is expected that absolute values derived for cohesion will be accurate to within 100 Pa, and for friction angle to within 3°.

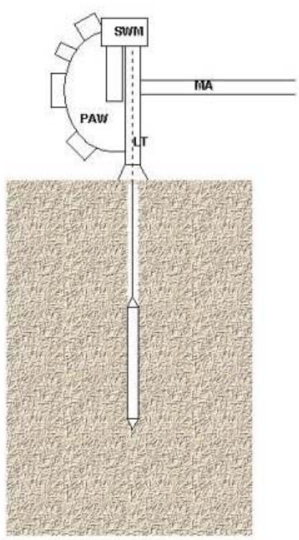

Fig. 3: Schematics of Mole downward deployment from the PAW instrument carrier at end of Beagle 2 mechanical arm.

Thermophysical Properties: A temperature sensor mounted on the Mole will support investigations of soil thermophysical properties and measurements of the subsurface temperature profile. Regolith temperature measurements will be conducted both as a function of depth during soil intrusion and retrievals, and as a function of time for constant depth, as the Mole can be left in the subsurface for periods of days before it is retrieved, especially during the later part of the Beagle 2 landed mission. Subsurface temperature data will support calibrations of Mars regolith thermophysical models, especially if coupled with thermal measurements conducted concurrently above the surface by sensors on the lander itself. Once soil thermal diffusivity is derived from the data, this can be solved for soil effective thermal conductivity using the bulk density estimates obtained from the PLUTO soil mechanics investigation, allowing in turn an estimate of the soil grain size regime from known correlations between thermal conductivity and grain size [7].

Volatile Condensations from Atmosphere: Provided the boreholes created by Mole soil penetration remain stable following retrieval of the device back to the surface, a search for condensed atmospheric volatiles along permanently shaded borehole walls will be conducted by periodic imaging with one of the lander camera heads being equipped with an illuminating torch. This will allow an independent estimate of the soil thermal conductivity to be derived, and would enable to constrain atmospheric water vapor content, utilizing simultaneous measurements of atmospheric pressure and temperature by sensors on the lander.

References: [1] Sims M.R.. et al. (1999) *Instruments, Methods, and Missions for Astrobiology II* , Proc. Internat. Soc. for Opt. Engnrg., Proc. Series, 3755, pp. 10-23. [2] Richter L. et al. (2002) *Planetary and Space Science* 50, pp. 903-913. [3] Morgan, G. et al. (2003) *EGS XXVIII*. [4] Klein H.P. (1978) *Icarus* 34, pp. 666-674. [5] Stoker C.R., and Bullock M.A. (1997) *JGR* 102 E5, pp. 10,881-10,888. [6] Tokano T. and Richter L., *Icarus*, submitted. [7] Presley M.A., and Christensen P.R. (1997). *JGR* 102 E4, pp. 9,221-9,229.