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Digging deep for ice in Isidis Planitia—New constraints on subsurface volatile concentrations from thermal modeling

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Abstract

The Isidis Planitia region on Mars usually is regarded as a comparably attractive site for landing missions based on engineering constraints such as elevation and smooth regional topography. The Mars Express landed element Beagle 2 was deployed to this area, and the southern margin of the basin was selected as one of the backup landing sites for the NASA Mars Exploration Rovers.

Especially in the context of the Beagle 2 mission, Isidis Planitia has been discussed as a place which might have experienced a volatile-rich history with associated potential for biological activity [e.g. Bridges et al., 2003. Selection of the landing site in Isidis Planitia of Mars Probe Beagle 2. J. Geophys. Res. 108(E1), 5001, doi: 10.1029/2001JE001820]. However the measurements of by the GRS instrument on Mars Odyssey indicate a maximum inferred water abundance of only 3 wt% in the upper few meters of the surface [Feldman et al., 2004. Global distribution of near-surface hydrogen on Mars. J. Geophys. Res. 109, E09006, doi: 10.1029/2003JE002160]. Based on these measurements this area seems to be one of the driest spots in the equatorial region of Mars.

To support future landing site selections we took a more detailed look at the minimum burial depth of stable ice deposits in this area, focusing as an example on the planned Beagle 2 landing site. We are especially interested in the likelihood of ground ice deposits within the range of proposed subsurface sampling tools as drills or 'mole'-like devices [Richter et al., 2002. Development and testing of subsurface sampling devices for the Beagle 2 Lander. Planet. Space Sci. 50, 903–913] given reasonable physical constraints for the surface and near surface material.

For a mission like ExoMars [Kminek, G., Vago, J.L., 2005. The Aurora Exploration Program—The ExoMars Mission. In: Proceedings of the 35th Lunar and Planetary Science Conference, abstract no. 1111, 15–19 March 2004, League City, TX] with a focus on finding traces of fossil life the area might be of potential interest, because these traces would be better conserved in the dry soil. Modeling and measurement indicate that Isidis Planitia is indeed a dry place and any hypothetical ground ice deposits in this region are out of range of currently proposed sampling devices.

Keywords: Mars; Water; Ice deposits; Beagle 2; ExoMars; Exobiology

1. Introduction

Isidis Planitia is interpreted to be an ancient impact basin and is situated at the highland–lowland boundary, possibly having been filled by sediments from drainage leading into this area. It has been suggested that this sedimentary material may still be volatile-rich (Bridges et al., 2001).

For this reason it is worthwhile to study this region in greater detail. In this study, we have focused on the likelihood of near-surface ice deposits, which might be important for the exobiological potential of this area in terms of favorable conditions for the preservation of organic molecules and biomarkers from putative early Martian life (e.g. McDonald et al., 1998). We present here estimates for the minimum burial depth of ground ice deposits, which are stable over long periods of time (>10 ka) for the Beagle 2 landing site. We have used the Berlin Mars near Surface Thermal model

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(BMST) (Helbert and Benkhoff, 2003) to derive a map for the minimum burial depth of possible ice deposits.

Beagle 2, the lander of the ESA Mars Express mission, was scheduled to land in the Isidis Planitia basin in December 2003. It would have repeatedly probed the near-surface regolith to depths of 2 m with a mechanical 'mole' for sampling and thermal measurements (Richter et al., 2002). Unfortunately, no signal was received from the lander and it was declared lost. Therefore we cannot compare predictions from our model with in-situ results. However, we have compared the modeled surface temperatures with measurements from the Planetary Fourier Spectrometer on the Mars Express orbiter (Helbert et al., 2005).

As a result of our study it should be noted that from a scientific point of view, especially focusing on volatile-related issues and extant life, Isidis Planitia is a less favorable location. Based on our results ice can only be stable at depths of 4.5 m and below. If the focus is however on traces of extinct life, Isidis Planitia might indeed be an interesting landing site. The dry soil which has been most likely free of ice for most of the history of Mars might have conserved traces of life from the very early phase of Mars history. This would apply especially to ExoMars, the first mission in the ESA Aurora program (Kminek and Vago, 2005). The rover is supposed to search for traces of past and present life and will most likely be equipped with a drilling device, giving access to the first meters below the surface.

The results on the ice stability are in agreement with findings by the GRS instrument on Mars Odyssey, which suggest a maximum inferred water abundance of 3 wt% for this area (Feldman et al., 2004) while noting that measurement depth of this instrument is no more than 1 m.

2. The BMST model

The BMST model is characterized by a high vertical resolution—down to the centimeter range—, a realistic treatment of the thermal properties of ice–rock mixtures, a detailed treatment of the gas flux within the surface and into the atmosphere and a variable temporal resolution which allows studying diurnal as well as seasonal variations. While most thermal models for the near-surface layer of Mars in use today assume constant physical properties with depth, this model is based on a layered structure of the subsurface material in which each layer can have different physical and thermo-physical properties.

The model includes a detailed treatment of the energy transfer into and out of the surface, including energy transported by gas flux and energy required for sublimation and energy released by recondensation of volatiles within the regolith. The model simultaneously solves the time-dependent mass and energy equations for the different volatiles. Solar energy input varies due to orbital and rotational motion of the planet. Heat is transferred into the interior of the regolith by solid-state heat conduction in the dust–rock–ice mixture (matrix) and by vapor flowing through the porous matrix. The gas flow from the sublimation fronts is driven by vapor pressure gradients. The numerical details of the model are discussed in Helbert and Benkhoff (2003).

The simplified sketch in Fig. 1 shows the working principle of the BMST, the so-called 'dirty ice approach'. The modeling is started assuming a porous layered soil in which the pores to a certain percentage are filled with ice. For this study only H_2O ice has been included, but CO_2 can be added as well. We have also neglected adsorbed phases for this study, as they have little influence on the effective depth of the ice table (Schorghofer and Ahardson, 2005). During the simulation, the thermal behavior, the energy transport and the gas flux within the soil are calculated over a number of Mars years. The thermal conductivity of each soil layer is in each step recalculated based on the ice content within the pores.

In the version used here the BMST approximates the atmosphere interaction by assuming a constant water content of the atmosphere as derived from the data by Smith (2002). The simulation continues until the model has reached a dynamic steady state. Dynamic steady state is defined by an annual repetition of the temperature gradients within the subsurface and by a stabilization of the predicted ground ice table. Typically, steady state is reached after 1000 or more Mars years for the region studied here.

From the distribution of ice with depth obtained upon convergence of the model, a predicted minimum depth of the ice table can be derived. Ice deposits stable over several annual cycles are possible only for depths in which the model predicts an ice content of the pores. For all other depths any existing ice would sublime over time. The version of the model used here does not consider diurnal frost deposits, which might occur at or very close to the surface.

From the data set of the Gamma-Ray Spectrometer (GRS) on Mars Odyssey we have a limited knowledge of

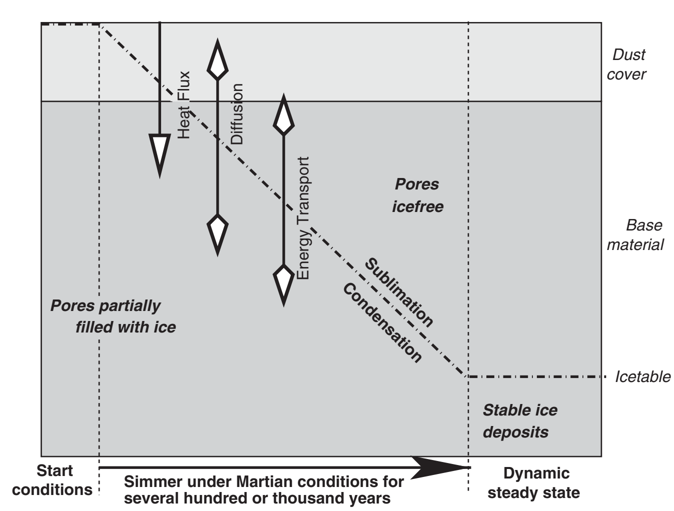

Fig. 1. The 'dirty ice' approach used in the BMST.