SIMULATIONS OF ROVER BASED NEUTRON REMOTE SENSING OF PERIGLACIAL FEATURES ON MARS

C.J. Hardgrove[1], J.E. Moersch[1], D.M. Drake[1] [1] Department of Geological Sciences, University of Tennessee, Knoxville, TN. 37996

Introduction: Results from Mars Odyssey's high-energy neutron spectrometer, and gamma ray spectrometer have shown that there is 15 to 20% ice in the top meter of Martian regolith at latitudes of +/-55 degrees [1,2,3]. This observation has been critical in understanding the nature of patterned ground on Mars [4]. The resolution of the ground ice maps generated from these instruments, however, is approximately 600 kilometers per pixel, which does not allow the details of specific patterned ground features such as ice- or sand-wedge polygonal cracks to be detected. One way to drastically improve the spatial resolution of neutron spectrometer measurements is to bring the detector to the surface. Many future rover missions, such as the 2009 Mars Science Laboratory, will include neutron spectrometers as part of their instrument suite. By acquiring data along traverses during normal mission operations, a rover-borne neutron spectrometer can generate high-resolution hydrogen maps of the local subsurface. Our goal is to show that local subsurface enrichments or depletions of hydrogen can be detected and that, in the case of polygonal cracks, the observed hydrogen content can be used to suggest a method of formation. In addition, knowledge of the present ice content in the cracks may provide clues about the past Martian climate and ground-ice abundance. Here we present the preliminary results of our study to determine the suitability of a rover-borne neutron detector for studying the structure and composition of polygonal cracks. We have simulated a neutron detector's traverse across several uniform-composition cracks of fixed dimensions. The specific instrument modeled is a prototype neutron detector built under the Mars Instrument Development Program. A description of the electronics and operation of the detector has been described in several sources [5, 6]. Field tests with the detector will also be described in Piatek et. al [7].

Background: Recent observations of latitudes poleward of +/- 55 degrees made with the Mars Orbiter Camera reveal small-scale cracks that are most likely the result of periglacial processes [8, 9, 10, 11, 12]. One type of patterned ground, polygonal cracks, is widespread throughout the high latitudes of Mars. A comprehensive study of patterned ground on Mars showed that there are several classes of polygonal cracks [4]. Based upon their variability in size, topography and geometry, it was argued that there is no single origin for all polygonal cracks on Mars, that they occur at latitudes where ground ice is present in the top meter of regolith, and that the cracks are geologically young (~1 Myr), but may not be presently active [4]. The range of polygon widths on Mars varies from typical terrestrial values of 15 to 30 meters to as large as 10 kilometers. The largest polygons, with crack spacings from 5 to 10 kilometers wide, appear to have a tectonic origin [13]. By contrast, smaller polygons, on the order of 15 to 50 meters wide, are commonly formed by periglacial processes in a manner similar to terrestrial polygonal cracks. The spacing of the cracks depends upon the penetration depth of the seasonal thermal wave, which is between 3 and 5 meters for both Earth and Mars. Therefore, polygons that are not of tectonic origin are expected to have a similar width and depth to those found on Earth.

On Earth, polygonal cracks can form by desiccation of clay-rich deposits or the action of specific tectonic stresses. Cracks may also be formed in periglacial regions where there is permanent ground ice in the top meter of regolith. These types of cracks form by freeze-thaw, frost-heave or thermal contraction of an ice-cemented regolith. The key requirement in each of these methods is the presence of ice-cemented regolith. It has been shown that if such a regolith exists at high latitudes on Mars, seasonal temperature variations would result in thermal contraction, creating tensile stresses great enough to form small-scale polygonal cracks [14]. This suggests that polygonal cracks are controlled by climate conditions, and more importantly, are the result of ground ice in the top meter of the Martian surface. Polygonal cracks can also remain present, but inactive under climate conditions in which they did not form, making them records of both climate and ground ice history. Measurements of the ice content within the cracks may provide clues about the past Martian climate and the abundance of ground ice during their formation. Measurements of subsurface hydrogen content between the cracks (interiors of the polygons) can also help constrain their mode of formation. Using ice/rock mixture ratios determined by a neutron detector, laboratory experiments (similar to those described in [15]) may be conducted to determine whether the viscosity of the regolith is large enough to promote propagation of incipient fractures. If it is not, then this may be an indication that the cracks were formed in a past Martian climate or that ground ice abundances have changed.

Simulations: Rover-borne neutron measurements are simulated using the Monte Carlo Neutral Particle extended (MCNPX) code to track the collision histories of neutrons in a two-layer subsurface model composed of Pathfinder-composition regolith with the addition of 15% ice by mass below a 15-cm-thick desiccated layer. Subsurface ice to rock mixing ratios, as well as crack geometry, may be varied as free parameters. Within the regolith, a simulated vertical crack is placed at depth with variable ice content [Figure 1]. The model is intended to show that such a feature can be detected by the neutron spectrometer and that an approximate ice to rock ratio can be derived for the surrounding regolith.

Two cases are modeled: 1) a crack formed by ice-wedging that has subsequently been buried and 2) a desiccated crack formed by thermal contraction. Real cracks form by the action of both processes, however these simulations are representative of end-member cases. For the ice-filled crack, pure water-ice is used. The depth of burial will depend upon the assumed ice table stability model. We adopt the modest burial depth of 15 centimeters at +/- 55 degrees latitude from Mellon (2006) [16]. The geometry of the crack is based upon polygonal S2 and S3 cracks described by Mangold et al. (2005), which have polygon widths between 15 and 30 meters and crack widths below the resolution of the Mars Orbital Camera [4]. Recent HIRISE imagery shows polygons of similar size having crack widths of approximately two meters or less [17]. Theoretical results from Parker [18] show the width of a polygonal crack is about three times the maximum depth of propagation for first-order cracks, therefore, for a polygon width of 15 meters the modeled crack depth is 5 meters.

Results: The results presented in Figure 2 show that cracks containing pure ice can be easily distinguished from desiccated cracks. There are also clear variations in the count ratio for various ice to rock proportions in the surrounding regolith, suggesting it is possible to determine if the viscosity of such a mixture is sufficient to produce brittle fracture.

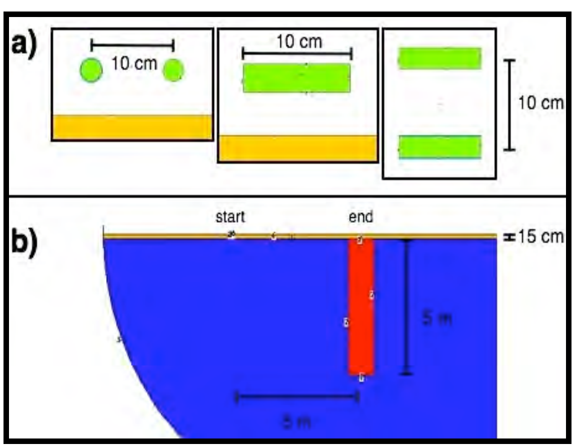

Figure 1: Simulation geometry a) shows cross sections of the detector tubes, while b) shows the crack (red) with start and end points of the traverse labeled.

Conclusions and Future Work: If the cracks were generated by freeze-thaw, then they should have been widened by the cyclical re-supply of ice in the

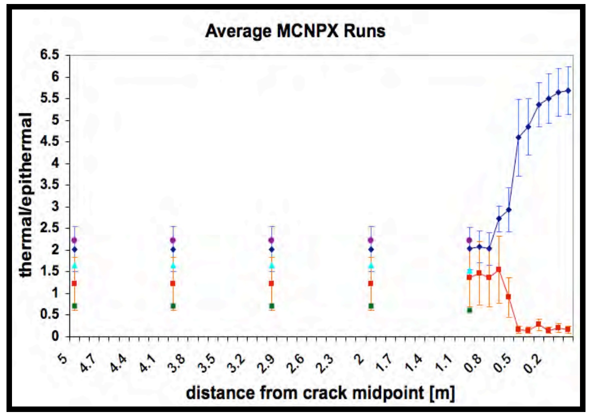

Figure 2: MCNPX thermal/epithermal count ratios for several traverses toward an ice-rich and desiccated crack (start position at left). *blue line:* traverse toward a pure water ice filled crack; *red line*: traverse toward a desiccated crack; approaches toward a desiccated crack are shown with 5% (*green points*), 30% (*cyan points*) and 50% (*purple points*) ice in the regolith.

permafrost layer during summer. An enriched hydrogen signature in the cracks relative to the surrounding regolith would suggest that ice-wedging was a factor in their formation and that freeze-thaw conditions for water were realized near the surface of Mars as recent as 1 Myrs ago, based on crater-count ages of the features [19]. If, however, a diminished hydrogen signature is found in the cracks relative to the inter-crack terrain, it may indicate that the cracks were formed by thermal contraction, and were subsequently in-filled with aeolian deposits in an arid climate. Desiccated cracks may also be consistent with ice-wedging if sublimation of the ice resulted from climate change [20].

Future simulations will model cracks with variable ice content, as well as examples of other patterned ground features. Field tests with our prototype neutron detector in terrestrial periglacial regions will help constrain future models and will be necessary for interpretation of results from any rover-borne neutron detector mission.

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