SPECTRAL EVIDENCE FOR LIQUID WATER ON MARS. N. O. Renno[1] and M. Mehta[2], [1]Department of Atmospheric, Oceanic, and Space Sciences, The University of Michigan, Ann Arbor, MI 48109, renno@alum.mit.edu, [2]Aerosciences Branch, NASA Marshall Space Flight Center, Huntsville, AL 35812.

Introduction: Determining if liquid water, a basic ingredient for life as we know, exists in other planets is an important goal of space exploration[1]. The recent discoveries of evidence for liquid water on acient Mars[2], and for interfacial water[3,4], liquid brines[5,6], and methane[7] today have excited the science community. Here we show spectral evidence that liquid saline water currently forms temporarily on Mars. This discovery supports the hypothesis that freezing/thaw cycles lead to the formation of brine pockets where ice and salts coexist in the shallow martian subsurface[6]. This is important because a diverse array of terrestrial micro-organisms thrives in brines[8].

Background: A few scientists from the Phoenix mission initially debated the discovery of liquid saline water[6] because one instrument (the Thermal Electrical Conductivity Probe, TECP) did not detect any evidence for liquid water in the regolith and there were no evidence for salts at the landing site. However, even after a careful analysis of data from the Phoenix Wet Chemistry Laboratory (WCL) led to the unexpected discovery of perchlorate salts[9], some were still unconvinced that liquid water had been discovered, perhaps because the goal of the mission was to search for evidence of liquid water in the distant geological past, not on present day Mars. Now, independent evidence supporting the discovery of liquid water has been mounting[10-14]. This is exciting because liquid water has important implications for exobiology, geochemistry and glaciology. Here we report the discovery of the spectral evidence for liquid water in flow-like and pond-like features of Mars polar region[11]. This suggests that liquid saline water forms sporadically on the surface and should be common in the shallow subsurface.

Analysis: The diffuse component of light scattered from wet surfaces is reduced by an amount proportional to the inverse of the square of the index of refraction[6,11]. Since the index of refraction of liquid water is larger than that of water ice, liquefaction darkens water substance. Liquefation reduces scattering because changing the medium covering the surface from air to water decreases the relative index of refraction between the surface and its surroundings. This increases forward scattering and produces reflections at the liquid-air interface, causing the wet surface to absorb more light than the dry. These effects have been studied extensively on earth because changes in albedo play an important role on climate. For example, it is well known that the reflectance and therefore the albedo of sea ice decreases when it starts to melt in the summer, increasing in the absorption of solar radiation and accelerating the melting[11].
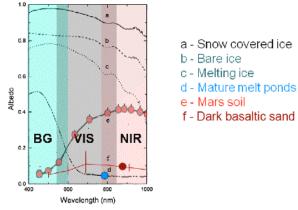

Fig. 1. Albedo of (a) snow-covered sea ice, (b) glazed-snow over sea ice, (c) bare sea ice, (d) melt ponds, (e) Mars polar soil, (f) Mars dark soil (basaltic sand)[11]. The colors represent HiRISE blue-green (BG), visible (VIS), and near-infrared (NIR) spectral bands.

More interestingly, measurements of the reflectance in different directions and therefore the albedo at the blue green (400-600 nm) and near infrared (780-1060 nm) portions of the spectrum show that ice, snow and soil have reflectances and albedo approximately constant with wavelength and that the reflectances and albedo of brines (melt ponds in sea ice) peaks at approximately 400-500 nm and decreases by almost an order of magnitude beyond 700 nm (Fig. 1)[11]. This happens because the absorption coefficient of liquid water is more than two orders of magnitude larger at near infrared than at blue green[15]. In contrast, the reflectances and albedo of typical Mars soil is larger at near infrared, because it is rich in iron[11]. Thus, the reflectances in a given direction or albedo at various portions of the spectrum, can be used to fingerprint liquid brines because it distinguishes them from frost, ice, snow, and soil[11].

It follows from the above that the broadband spectral parameter

$$\eta \equiv \frac{a_{NIR} - a_{BG}}{a_{NIR}}, \qquad (1)$$

where a_{NIR} and a_{BG} are either the albedo or reflectance, in specific directions, at near-infrared (NIR) and blue-green (BG), can be used to distinguish liquid brines from frost/snow and Mars soil. Table 1 indicates that $\eta \cong -6$ to -8 is a fingerprint of liquid brines because none of the substances likely to be present at the surface of Mars have η with value this low[11]

Material	η
Brines	-8 to -6
Frost/Snow	-1.5 to 0
Mars Soil	0.5 to 1

Table 1. Broadband spectral signature of brines, frost/snow, and Mars soil derived from Fig. 1.

In order to remove atmospheric effects and quantify the reflectance of Mars surface, we propose the procedure described next[11]. Recall that the reflectance at wavelength λ is defined as

$$R_\lambda = \frac{\pi I_\lambda}{F_\lambda}, \qquad (2)$$

where F_λ and I_λ are the radiances at wavelength λ incident at the surface and reflected by it. The reflected radiance can be calculated using the measured brightness intensity, or instrument digital number (*DN*), with the aid of the instrument calibration function[11]

$$I_\lambda + I_\lambda^{path} = aDN + b, \qquad (3)$$

where I_λ^{path} is the net source of radiance (emission plus scattering, minus absorption) at wavelength λ integrated along the surface-instrument path, and a and b are the instrument gain and offset.

Taking the radiance reflected from the darkest pixels on shadows to be $I_\lambda \cong 0$, it follows from Eqn (3) that

$$I_\lambda = a\left(DN - DN_{dark}\right). \qquad (4)$$

Substituting Eqn (3) into (2), we get

$$R_\lambda = \frac{\pi}{F_\lambda}\left(aDN + b - I_\lambda^{path}\right). \qquad (5)$$

Thus, the reflectance of pixels dominated by ice is

$$R_\lambda^{ice} = \frac{\pi}{F_\lambda}(aDN_{ice} + b - I_\lambda^{path}), \qquad (6a)$$

and the reflectance of dark pixels dominated by shadows is

$$R_\lambda^{dark} = \frac{\pi}{F_\lambda}(aDN_{dark} + b - I_\lambda^{path}). \qquad (6b)$$

Taking $R_\lambda^{dark} \cong 0$, it follows from the above that

$$R_\lambda = R_\lambda^{ice}\left(\frac{DN - DN_{dark}}{DN_{ice} - DN_{dark}}\right). \qquad (7)$$

Eqn (7) can be used to adjust the reflectance of each pixel of the images of features of interest. We use it to obtain quantitative reflectance values. The reflectances of ice at the spectral bands in consideration, measured in the laboratory[11], are used for R_λ^{ice} in our calculations. The error in the reflectance calculation is

estimated to be of the order of 10 %[11]. HiRISE images of flow-like and pond-like features on polar dunes[3,4,11] are analyzed by visually finding the brightest 25-50 pixels indicating frost/snow, the 25-50 darkest pixels in the darkest shadows, and adjusting the reflectance of each pixel with the aid of Eqn (7). Fig. 2 show that this analysis unveil the fingerprint of liquid water on Mars. Deliquescence occur in frost-covered areas that the temperature exceeds the eutectic temperature of salts in contact with it, before frost sublimates. This implies the existence of an optimum zone in the polar region where deliquescence occurs seasonally and produce surface flows and puddles of liquid saline water.
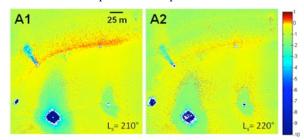

Fig. 2. Spectral fingerprint of brines on Mars polar region. These images were obstained by applying Eqn. (7) to the following HiRISE images. NIR images of files PSP_003175_1080 and PSP_003386_1080, as well as BG images of files PSP_003175_1080 and PSP_003386_1080 and then the value of η is calculated for each pixel[11].

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