THERMAL INERTIA ANALYSIS OF THE SURFACE AND NEAR-SURFACE OF 4 VESTA. T. N. Titus[1], F. Tosi[2], J.-Y. Li[3], M.T. Capria[2], M. C. De Sanctis [2], C. T. Russell[4], [1]USGS Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ (ttitus@usgs.gov), [2]Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, Rome, Italy, [3]Planetary Science Institute, Tucson, AZ, [4]Institute of Geophysics and Planetary Physics, University of California at Los Angeles.

Introduction: The Dawn spacecraft [1], which will be the first spacecraft to orbit and study two different solar system bodies (excluding the Earth-Moon system), has already provided a wealth of observations of the surface of the asteroid 4 Vesta, and is currently en route to the dwarf planet 1 Ceres. These two differentiated bodies may represent distinct endmembers when it comes to the presence of near-surface volatiles; Vesta orbiting on the inside of the solar system "snow line" and Ceres orbiting outside. This idea has been proposed and explored by many researchers (e.g., [1-4]) and was among the stronger scientific motivations behind the Dawn mission [1]. This paper reviews the recent observations of Vesta's surface thermal inertia and implications for the possibility of near-surface ice.

Temperatures and surface thermal inertia of Vesta: The surface temperatures of the asteroid 4 Vesta have been measured by the Dawn spacecraft's [1] Visible and Infrared mapping spectrometer (VIR) [5]. Temperatures were determined using a Bayesian approach to nonlinear inversion combined with Kirchhoff's Law and the Planck function [6]. The minimum retrievable temperature in VIR data is ~180 K, which essentially means that only daytime temperatures can be measured. Temperature maps have been reported both for broad regions of Vesta [7] and for specific sites seen only at the local scale [8, 9].

Thermal inertia is the thermal equivalent of Bond Albedo; it is an intrinsic property of the surface and is fixed unless the material properties are altered. Temperatures, on the other hand, while dependent on thermal inertia, vary throughout each diurnal and seasonal cycle, just as reflected radiance changes with viewing angles and illumination due to slopes and local times.

Thermal inertia of a surface is determined by grain-size, composition and state of cementation. Estimates of thermal inertia can be used to constrain other observations and determine near-surface temperatures. For example, estimates of near-surface annual mean temperatures aid in the interpretation of observations from other instruments, such as the detection of excess hydrogen by Gamma Ray and Neutron Detector(GRaND) [10].

In this work, we compare Vesta's observed surface temperatures with results obtained with the KRC thermal model [11]. Regions of higher thermal inertia are identified as possible areas of dust-free regolith. Model fits can then be used to estimate near-surface temperatures which provide important constraints for the stability of surface and near-surface volatiles, especially H_2O.

Table 1: Parameters used in Thermal Models.

	Vesta	Reference
Bond Albedo	0.1-0.35	[12]
Thermal Inertia	11-42	[13, 14]
Slopes	0-40 Degrees	[15]
Emissivity	0.9	[16]
Roughness	0-1	[14]

Data & Processing: We used observations from the Dawn spacecraft to determine thermal inertias presented in this paper. Daytime temperatures are derived from VIR [7]. Bond Albedo is estimated from the calibrated Framing Camera (FC) albedo mosaic [12]. Slopes are derived using Gaskell's shape models [15]. Locations (latitude, longitude) were determined using the USGS Integrated Software for Imagers and Spectrometers (ISIS) software package [17-20].

Thermal Inertia Estimates: A suite of thermal models are generated using KRC [11]. Temperatures returned from these models are stored in an 8-dimensional lookup table where each input parameter is a dimension. The dimensions are: season, local time, latitude, slopes (aspect and magnitude), Bond Albedo, effective emissivity (emissivity and roughness), and thermal inertia. Each VIR temperature image is processed separately. Because these thermal-inertia estimates are based on a single time of day (usually within an hour of local noon) and season, thermal inertia and effective emissivity cannot both be uniquely determined.

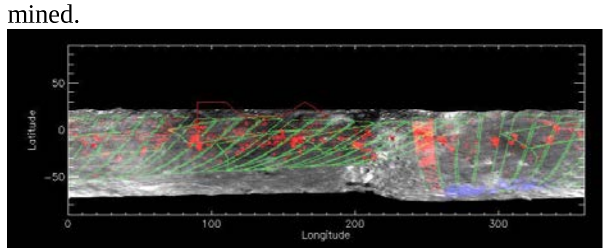

Figure 1: Mosaic of dust-free regolith (red) and potential permafrost (blue). The images used for this mosaic are outlined in green. The region outlined in red is where GRaND detects excess hydrogen. This mosaic uses the Claudia coordinate system.

Correcting the image for local effects (e.g., slopes and Bond albedo), a best-fit effective emissivity and thermal inertia is determined for the entire image. The effective emissivity is then fixed and thermal inertia is determined pixel-by-pixel. In some cases, the observed temperature cannot be fit using the pre-determined emissivity with the range of model thermal inertia (11-42). In this case, the thermal inertia is fixed to 42 for cold pixels and 11 for hot pixels. The effective emissivity becomes the model-fitting parameter.

Results for Vesta: Using survey data [1], a distribution of thermal inertia can be mapped and mean annual subsurface temperatures can be determined. For the purposes of this abstract, areas with thermal inertia at (or above) 42 are considered to be dust-free regolith (red in Fig. 1, and occur across a wide range of slopes and albedo.

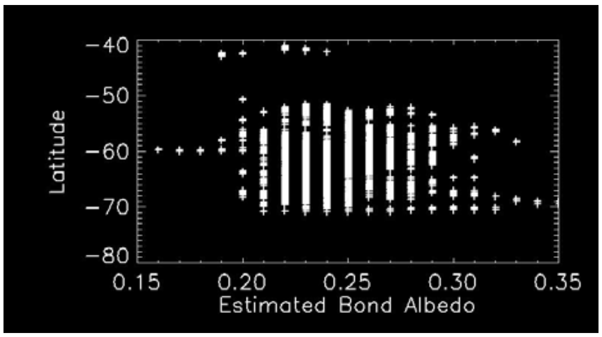

Figure 2: Slopes vs. Bond Albedo for regions identified as potential permafrost.

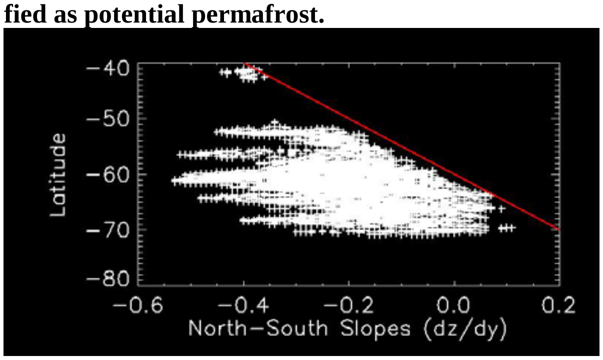

Figure 3: Latitude vs North-South slopes for regions of potential permafrost.

The second parameter mapped in Fig. 1 shows regions where the estimated annual mean temperature remains at or below 145 K. These are regions where subsurface conditions are cold enough for H_2O ice to be stable over the lifetime of the solar system [21]. These regions, marked in blue, only occur at mid-to-high latitudes and only on surfaces with a Bond albedo > 0.20. None of these regions correspond to the equatorial area where GRaND detected excess hydrogen [10]. GRaND observations, when constrained by near-surface temperatures, suggest that Vesta does not have any large H_2O ice deposits at or near the surface. However, small isolated deposits may be possible in the near-surface where the surface is bright (Albedo > 0.2 (see Fig. 2)) and the slopes are poleward facing (see Fig. 3).

Future work for Vesta: The thermal-inertia range used in the forward models must be increased. Even at survey resolutions, small regions are identified that have thermal inertia greater than 42. Updated results from the survey phase and new results from the high altitude phases of the mission will be presented.

Conclusions: While the possibility of small deposits of H_2O ice exists in the near-surface of Vesta on bright mid-to-high latitude poleward-facing slopes, it is unlikely there are any large deposits of ice present today since the areas where GRaND observes excess hydrogen are regions where the subsurface is too warm for ice to be stable.

Need for ground-based observations: Continued ground-based (e.g., Keck AO or ALMA) and future Earth-orbiting satellite (e.g., James Webb Space Telescope) observations are needed for Vesta. The Dawn spacecraft only measured daytime surface temperatures over about a third of Vesta's orbit, so to fully characterize the thermal properties of Vesta's surface, telescopic observations of surface temperature will be needed to supplement the VIR observations.

Acknowledgements: The authors gratefully acknowledge the support of the Dawn Instrument Operations, the Science Teams and the Italian Space Agency. This work was partially supported by NASA through the Dawn project and the Dawn at Vesta Participating Scientists program.

References: [1] Russell, C.T., et al., *P&SS*, *52*, 465–489, 2004. [2] Thomas, P. et al. (2005) *Nature*, *437*, 224 [3] McCord, T. and C. Sotin (2005) *JGR*, *110*, E05009 [4] Vernazza, P. et al. (2005) *A&A*, *436*, 1113. [5] De Sanctis, M.C., et al. (2011). *Space Sci. Rev.*, 163, 329–369. [6] Keihm, S., et al. (2012). *Icarus 221*, 395-404. [7] Tosi et al. (2014), Workshop "Vesta in the Light of Dawn", 3-4 Feb 2014, Houston, TX. [8] Tosi, F. et al (2014). *Icarus*. In review. [9] Tosi, F. et al. (2013*) LPS XLIV*, p.1917. [10] Prettyman, T et al. (2012) *Sci., 338*, 242. [11] Kieffer et al., (1977) *JGR*, *82*, 4249-4291. [12] Li, J.Y. et al. (2013) *Icarus*, *226*, 1252. [13] Li, J.Y. et al. (2006) *Icarus*, *182*, 143. [13] Capria, M.T. et al. (2013) *EPSC*, *8*, 976. [14] Titus et al. (2012) *LPSC*, *44*, 2400. [15] Gaskell, R. W. (2012) *DPS*, *44*, 209.03 [16] Leyrat. C. et al. (2012) *A&A*, *539*, 154. [17] Gaddis et al. (1997) *LPSC 28*, 1226 [18] Eliason et al. (2001) *LPSC 32*, 2081. [19] Becker et al. (2012) *LPSC 43*, 2892 [20] Anderson, J. et al. (2011) *AGU*, U31A-0009. [21] Schorghoffer & Aharonson (2005) *JGR,115*, 5003.