CORRELATING REMOTELY-SENSED NIGHTTIME THERMAL RADIANCE IMAGES WITH FIELD-MAPPED GEOLOGIC UNITS: A TERRESTRIAL CASE STUDY WITH APPLICATIONS TO MARS. S. C. Whisner and J. E. Moersch, Dept. Earth and Planetary Sciences, The University of Tennessee, Knoxville, TN 37996-1410, geowhis@utk.edu

Introduction: Visible and infrared spectral remote sensing are often used to map geology. However, these techniques are only sensitive to a depth equivalent of a few times the wavelength (several 10's of microns at most). This creates a problem when there is an obscuring layer on top of the geologic units of interest. On Earth the most common example of such a layer is vegetation. On other planets, fine regolith can be equally obscuring of underlying spectral properties related to geologic units. One way around this problem is to use nighttime thermal infrared temperature images to map geologic units. The sensing depth of this type of data is approximated by the diurnal thermal skin depth (~10 cm for typical geologic surfaces), allowing one to "see below" spectrally obscuring surface layers, and to map underlying geologic heterogeneities. Temperature differences are related to differences in thermal inertia, which are, in turn, related to particle size, degree of induration, and (for Earth) moisture content. Rock compositions cannot be directly determined, but lithologic unit boundaries can be accurately mapped. With the advent of THEMIS (100 m) thermal infrared night imaging of Mars, the utility of this technique for lithologic mapping is becoming more apparent. However, very little has been done in the way of field verification of the technique on Earth. Here we consider one such case study, in the Southern Appalachians, where pervasive vegetative cover obscures underlying spectral differences, but nighttime thermal infrared (TIR) reveals much.

Using spectral data collected with the EOS-ASTER instrument we are able to differentiate among rock lithologies in the Valley and Ridge geologic province of southeast Tennessee. ASTER infrared and visible spectral data (manipulated with ENVI) were used to determine whether the unique spectral signatures of different rock types could be detected through the pervasive vegetative cover typical of the region using a multispectral sensor. Fortunately, this region has been mapped extensively [1], providing excellent ground truth for scene analysis. Differentiating between the two major rock types (carbonate-dominated outer portions and clastic-dominated synclinal core) was the most basic goal of this project. A more ambitious goal was to remotely locate boundaries between individual lithologic units. This is theoretically possible because most units are over 1000 ft (305 m) thick, and no individual lithologic unit thickness is less than 100 ft (30.5 m). These widths are well within the visible band resolution of the sensor and at the ground resolution of the short wave infrared (SWIR) and TIR bands. Similar studies using ASTER and other instruments [2], [3], have detected differences in lithologies and major structural features but on a much broader scale.

Study area: The Tellico-Sevier syncline is located in Paleozoic age rocks that have been deformed in the footwall of the Great Smoky fault in southeastern Tennessee [4] (Figure 1) between Knoxville and Chattanooga, TN. The core of the syncline is composed of sandstones and siltstones (reds and browns on Figure 1), whereas the outer portions are primarily carbonates (oranges) (shales are greens). The rocks are covered in large part by saprolite/colluvium from a few centimeters to up to a meter in thickness due to high weathering rates in the humid climate.

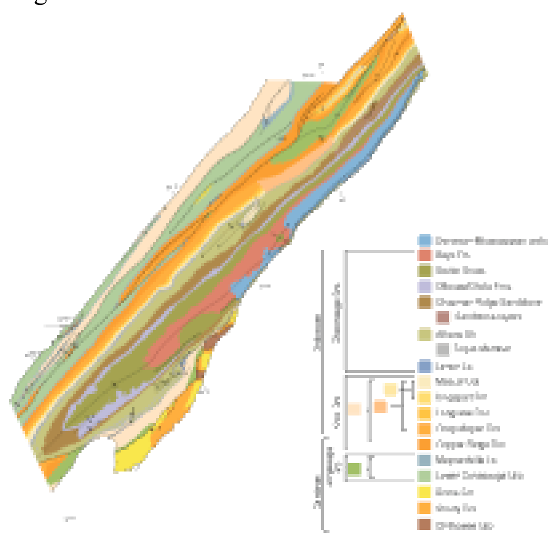

Fig. 1: Geologic map of the Tellico-Sevier syncline

Methods: A number of daytime ASTER scenes with little cloud cover were collected from a site that had been extensively mapped at 1:12000 scale. The visible and short wave infrared bands were enhanced by atmospheric removal but showed little compositional information about underlying rock units. Figure 2 shows radiant thermal energy of various substances over a 24-hour daily cycle. The rock response is generalized and does not indicate differences in thermal inertias between limestones (.045) and sandstones (.070). Water, although it has low thermal inertia (.036), has a high specific heat (1 cal/g/C°) compared to say, shale (.391 cal/g/C°) a common rock type in the study area (Figure 1), so it warms the air above it more than the rocks do. This causes the water to appear brightest on the thermal images.

Results: The visible and short wave infrared images showed vegetation and water but were of limited use for differentiating among various lithologies; the rocks were compositionally indistinguishable with the available spectral bands. However, even extremely subtle lithologic differences are evident in the nighttime thermal infrared image. For example, Figure 3 shows subtle changes in geology independent of vegetation effects under less than ideal conditions (temperate climate, mixed lithology units). The lighter areas correspond to warmer regions such as water and sandstones (white). The cooler regions correspond to shales and limestones (gray and black). The syncline is delineated by brighter pixels. A similar bright unit is apparent in the middle of the scene. These bright zones correspond to the location of sandstone ridges on the geologic map. We were not totally convinced this image showed anything more than topographic differences until we noted that a dark area caps the mountain at the southern tip of the scene. This mountain is composed primarily of quartzite and metaconglomerates but is topped by the Nichols shale (dark area), and a small "peninsula" of the overlying Nebo sandstone (bright) (left of A on Figure 3).

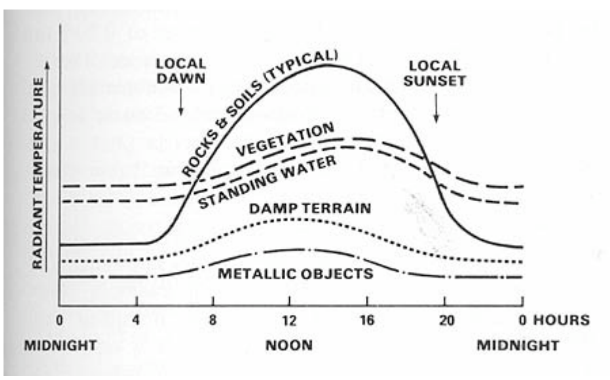

Fig. 2: Radiant temperatures of common materials over diurnal cycle [5]

Applications to Mars: These results are relevant both to other parts of Earth and to other worlds in detecting geologic, lithologic and structural variations that are obscured by surface cover. The visible and SWIR ASTER scenes of the southern Appalachians are dominated by vegetation effects. The same problem exists on Mars, but dust is the obscuring feature. Dust and vegetation spectral features overwhelm more subtle compositional spectral features in the shortwave infrared but have a spectral skin depth of only a few microns. Thermal features evident at night reveal deeper structural and lithologic differences, due to the greater sensing depth associated with diurnal thermal propagation. These thermal variations show mappable heterogeneities within the underlying rock and could be compared to what a field geologist might find on Earth. Similar problems were discovered at the MER landing sites where daytime THEMIS images are spectrally homogeneous, but nighttime thermal images show complexities beneath the surface [e.g., 5,6]. With similar imaging resolutions in the thermal infrared (ASTER 90 m) (THEMIS 100 m), a case can be made for the southern Appalachians nighttime thermal imagery as an analog for Mars nighttime thermal imagery. Variations in nighttime thermal infrared intensity can show tremendous detail both in lithology and structure that might easily be overlooked, even by a human mapper on the ground. However, without some sort of ground-truth, it is impossible to distinguish lithologically similar units in different stratigraphic locations. Despite the limitation, nighttime thermal infrared is a powerful first-order mapping tool. Our success in relating mapped thermal units in nighttime infrared images to true geologic maps based on extensive field work gives us increased confidence in the utility of similar thermal infrared techniques for mapping the geology of Mars, where little in the way of ground-truth mapping exists.

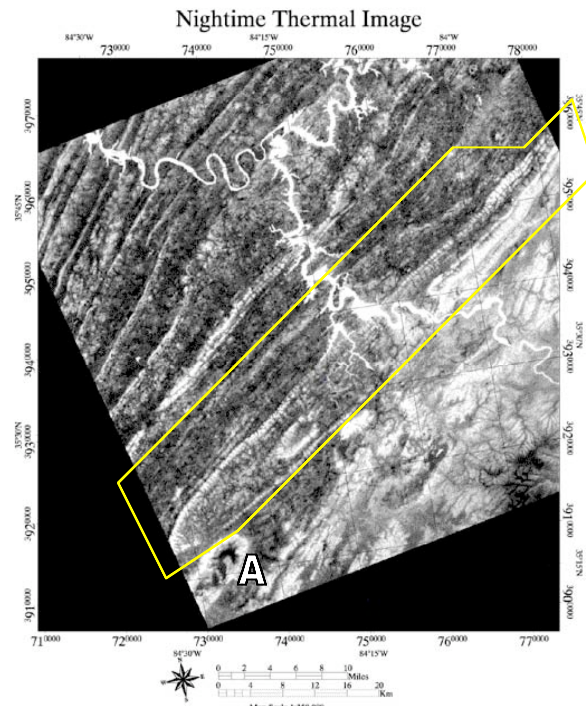

Fig. 3: Nighttime ASTER thermal image of Tellico Sevier syncline (map boundary outlined in yellow).

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