Investigations of Geologic Units and Structural Features on the flanks of Elysium Mons, Mars, Using Visible Images and General Thermal Signatures from THEMIS

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Abstract

On the northwest slopes of Elysium Mons, Mars, deep linear grabens (fossae) are sources for Early Amazonian-aged flow deposits. This region also contains faults, pit chains, impact craters and volcanic flows which make it an interesting site for geologic investigations using remotely sensed data. Thermal Emission Imaging System (THEMIS) has collected thermal infrared (IR) multispectral and visible to near-IR images of the surface and atmosphere of Mars since February 2002. While strongly affected by atmospheric and surface dust and not ideal for specific mineral detection, THEMIS can be used to understand volcanic, structural and surficial processes through its visual images and through gross thermal signatures obtained from its IR images. In this study, we learn to acquire and process IR and visible THEMIS data to investigate faults, pit chains, and outflow channels in the Elysium Fossae region of Mars.
Introduction

On the northwest slopes of Elysium Mons, Mars, deep linear grabens (fossae) are sources for Early Amazonian-aged flow deposits (Russell and Head, 2001, 2003). These flows are among the youngest of flows on Mars. This region also contains faults, pit chains, impact craters and volcanic flows which make it an interesting site for geologic investigations using remotely sensed data (Figure 1). The Thermal Emission Imaging System (THEMIS) has collected thermal infrared (IR) multispectral and visible to near-IR images of the surface and atmosphere of Mars since February 2002 (Christensen et al., 2003). While strongly affected by atmospheric and surface dust and not ideal for specific mineral detection, THEMIS can be used to understand volcanic, structural and surficial processes through its visual images and through gross thermal signatures obtained from its IR images. In this study, we plan to apply the THEMIS data along with other data from the Mars Orbiter Camera (MOC) and Mars Orbiter Laser Altimeter (MOLA) data to investigate faults, pit chains, and outflow channels in the Elysium Fossae region of Mars.

Geologic Setting

The Elysium rise borders the northern lowlands. Radial fossae occur on the flanks of this young Martian volcano. The morphology of fossae ranges from pit chains, to grabens, to wide gently curving troughs (Russell and Head, 2001). The fossae are within 15 radial degrees of Elysium Mons and outflow channels originate from some of the fossae. However, fossae having an elevation greater than -3500m are not origins of larger outflow channels. It is believed that dikes disrupted a confining cryosphere and channeled large volumes of groundwater to the surface (Russell and Head 2001, 2003). This release caused debris flows and lahars to occur and created channels from the Elysium Rise into the Utopia basin (Figure 1). Investigations of the outflow channels give an insight into past and current Martian hydrology.

Mars Data Sets and THEMIS

For surficial studies of Mars, remotely data sets include visual, multispectral, and hyperspectral images and topographic measurements. Visual images have been acquired by Viking spacecraft, the MOC camera on the Mars Global Surveyor, and the THEMIS instrument on board the Odyssey spacecraft. IR images have been collected by the Thermal Emission Spectrometer (TES) aboard the Mars Global Surveyor and THEMIS. Also, the Omega spectrometer on the Mars Express has collected hyperspectral data to investigate minerals and
Figure 1: The western and northwestern flanks of Elysium Mons and the southwest area of Utopia Basin. The image was created from a mosaic of Viking imagery (resolution ~240 m/pixel) overlaid with MOLA topographic data, color coded with reds representing highs, blues lows. The flanks of the volcano feature many pit crater chains and troughs from which groundwater outflow channels are emanating.
the composition of the atmosphere and Mar’s Express’s High Resolution Stereo Camera is collecting high resolution images and topography data.

The THEMIS instrument on board the Mars 2001 Odyssey spacecraft contains a 5-band visual imaging system and a 10-band infrared imaging system. The wavelengths of the IR multispectral images are between 6.5 and 15 microns and the visible to near-IR images have wavelengths between 450 to 850 nm. (Christensen et al., 2003). The IR bands are centered at 6.78, 6.78, 7.93, 8.56, 9.35, 10.21, 11.04, 12.57, and 14.88 microns and the visible bands are centered at 0.425 microns, 0.540 microns, 0.654 microns, 0.749 microns and 0.860 microns. The IR subsystem has a resolution of 100 m/pixel and the visual imaging system has a resolution of 19 m/pixel. The visible imaging of THEMIS provides an intermediate resolution between the image of the Viking and detailed images of MOC. While the TES instrument had collected hyperspectral images of the entire Martian surface, the THEMIS instruments provides IR data in a much higher spatial resolution. The THEMIS infrared imager will also image 100% of the planet at both day and night (Christensen et al., 2004).

In practice, scientists have typically limited their investigation and presentation of THEMIS images by using just band 9 for IR images and band 3 for visible images. Band 9 is considered to have the highest signal to noise ratio for the range of surface temperature on Mars. For visible images, band 3 is chosen because it is highly sensitive to albedo variations and the band is typically the clearest of the visible bands. Typically, the band 9 radiance observations in the IR images are converted to brightness temperatures. For comparisons made between images or when images are mosaiced together, the images are normalized to the maximum mean radiance found from all the images. In addition to calculating temperature, others have calculated thermal inertia from THEMIS IR data. This process involves using a lookup table of calculated variables for a given region such as albedo and temperature. Previously, thermal inertia has been calculated using data from TES. Thermal inertia maps of Mars have been created from TES data (Putzig et al., 2005; Mellon et al., 2000). These maps have a resolution of 20 pixels per degree and can be utilized to better understand THEMIS data for given study area.

The original goals of the THEMIS mission included determining the mineralogy of localized deposits (primarily in hydrothermal or subaqueous environments), finding subsurface hydrothermal systems, investigating 100-m scale processes, determining landing site characteristics, and studying polar cap processes (Christensen et al., 2003). The primary goal of finding evidence of recent geothermal activity has to date been unsuccessful. However, the high resolution temperature information provided by THEMIS has allowed insight into
many other aspects of Mars. THEMIS has been used to detect and investigate outcrops of exposed bedrock, ejecta from impact craters, landslides, sand and dust, surface compositional variations, and the formation and recession of polar caps (Christensen et al., 2003).

The use for mineral detection has been hampered by atmospheric errors and surface dust. THEMIS can see through only a small amount of atmospheric dust and even a thin layer of surface dust (~100um) will obscure any underlying thermal IR signatures (University of Arizona). Complex and simple correction methods for atmospheric errors have been developed (Bandfield et al., 2004a; Mustard, 2004; Anderson et al, 2005) and have been applied to correct THEMIS data to find minerals, including possible granitoid exposures in crater centers (Bandfield et al., 2004b). In addition, surface roughness and particle size cause spectral effects that can make mineral deposits difficult to detect from THEMIS images (Kirkland, 2003).

While the thermal signature of the surface rocks is obscured by atmospheric and surface dust, gross thermal signatures from THEMIS can be used to distinguish and map separate rock and surface units (Farrand, 2003; Pelkey, 2003; Keszthelyi et al., 2004). Here, we plan to use this ability of THEMIS, aided by MOC images and MOLA topography data, to investigate the geology and structures of the Elysium Mons and Utopia Basin region such as outflow channels, faults, pit chains, and craters (Figure 1-2).

**Data Acquisitions and Processing**

Five thermal infrared (I02167007RDR I05213010RDR I07017013RDR I07404019RDR I08521011RDR) and five visual (V02167008RDR V04414006RDR V05550017RDR V05912011RDR V06299019RDR) THEMIS images of the northwest flank of Elysium Mons were acquired from the THEMIS data distribution site (themis.asu.edu). Arizona State University hosts this server and provides access to the THEMIS data. Data has been released on regular intervals since October 2002 and most recently in January of 2005. The data is provided in three formats: i) a Raw Radiance cube file (EDR), ii) a Calibrated Radiance Cube file (RDR), and iii) an Apparent Brightness Record image for visual images or a Brightness Temperature Record for IR images. The Apparent Brightness Record is calculated from the band 3 of the visual data while the Brightness Temperature Record image is computed from band 9 of the IR data. While the EDR data contains the originally acquired data with errors, the RDR file contains the same full resolution THEMIS data but with corrections performed to removed duplicates and transmissions errors.
The Calibrated Radiance Cube files (or RDR QUBE files) were acquired for the 10 images which were then processed with the Integrated System for Imagers and Spectrometers (ISIS) software. ISIS is developed and maintained by the United States Geologic Survey. The USGS provides the software free of charge from their website (http://isis.astrogeology.usgs.gov/). The software is used to process data from spacecraft missions as well as perform many common image processing operations.

A series of commands in ISIS were used to process the QUB data files. First, we convert the QUBs into an ISIS file. We then process a simple cylindrical and a Mercator projection of this file. We output both projected files for use in other software packages, such as ArcGIS. For example to perform these conversions on a visual image named V0555017RDR and an IR image named I02167007RDR, the following commands were used:

```
#input the data into ISIS, define coordinate system as geographic, and output a RAW image
thm2isis.pl V05550017RDR.QUB.txt -- -- -- -- -- 180
thmvismc.pl V05550017RDR.lev1.cub -- -- -- SIMP:0,OCENTRIC
./isis2world_dd_slcfix.pl -e V05550017RDR.vismc.cub

#start ISIS command prompt and do the following commands
# to use a mercator projection with the latitude of true scale set at 30 degrees
# and write out a RAW image
lev2tolev2 from=V05450016RDR.vismc.cub mappars="MERC:30,0"
targdef="/array/isis/data/targets/mars.def.4" lonsys="180"
geom from= V05550017RDR.vismc.cub to= V05550017RDR merc.vismc.cub
./isis2world2.pl -e V05550017RDR merc.vismc.cub

#input the data into ISIS, define coordinate system as geographic, and output a RAW image
thm2isis.pl I02167007RDR .QUB.txt -- -- -- -- -- 180
thmirmc.pl I02167007RDR .lev1.cub -- -- -- SIMP:0,OCENTRIC
./isis2world_dd_slcfix.pl -e I02167007RDR .irmc.cub

#start ISIS command prompt and do the following commands
# to use a mercator projection with the latitude of true scale set at 30 degrees
# and write out a RAW image
tae: lev2tolev2 from=I02167007RDR .irmc.cub mappars="MERC:30,0"
targdef="/array/isis/data/targets/mars.def.4" lonsys="180"
```
In this project, 5 acquired visual images (V02167008RDR, V04414006RDR, V05550017RDR, V05912011RDR, and V06299019RDR) were processed. However, only 3 of the thermal infrared (I02167007RDR, I05213010RDR, and I07404019RDR) were processed. I07017013RDR and I08521011RDR were unable to be processed and the failure to do so in ISIS is currently not clear. V02167008RDR contains all 5 bands while the other visible images only contain band 3 (Figure 3). Images I05213010 and I02167007RDR contain all 10 bands while the nighttime image I07404019RDR contains bands 4, 9, and 10.

The THEMIS images that have been successfully processed now exist in both geographic and Mercator coordinate systems. The geographic projection allows us to see the images in the context with other data formats (Viking, MOC, MOLA) which have been previously processed and inputted into a GIS. By using a Mercator projection with a latitude of true scale of 30° N. we have tried to preserve distance and scale for potential analysis of structural and geomorphologic features in our study area.
Figure 2: 5 visual images (V02167008RDR, V04414006RDR, V05550017RDR, V05912011RDR, and V06299019RDR) and 3 of the thermal infrared (I02167007RDR, I05213010RDR, and I07404019RDR) of the western and northwestern flanks of Elysium Mons were acquired and processed. The images are overlain on a mosaic Viking imagery overlaid with MOLA topographic data as in Figure 1.
Figure 3: Band 1 through 5 of visual THEMIS image V02167008. Typically, band 3 is solely analyzed for visible Themis images. This band is chosen because it is highly sensitive to albedo variations and the band is typically the clearest of the visible bands.
Results

In performing this study, I completed the following steps: (i) reviewed the literature of this region and techniques for THEMIS analysis, (ii) acquired, processed and registered THEMIS image(s) in the region, and (iii) investigated gross thermal signatures of different geologic and structural features while looking for insight into the origin and relationship of such features. At project completion, significant progress has been made in reviewing the literature and also in the acquiring and processing of THEMIS images. An initial investigation using visible and thermal THEMIS images was performed on the northwest slope of Elysium Mons.

The analysis was limited to two IR and two visible images (Figure 4). Image analysis and display was performed in ENVI/IDL, Imagine, and ArcMap. The software was used to analyze the visible and thermal images looking for thermal signatures of the geology and to learn more information about the structures in this study. No atmospheric or topographic corrections were performed on these images.

Initial investigations on the general morphology and thermal signatures of the surface on Elysium Mons have been performed on sub areas in the THEMIS visible and IR images (Figure 4, 5, 6, 7, and 8). Correlation of temperatures and surface slope can be seen in both daytime visible and IR images (Figure 5, 8. Slopes facing the solar illumination are extremely bright while slopes facing the opposite direction are darker. This is very evident in impact craters where higher temperatures exist on the western sun-facing side wall of the crater while the east facing wall has lower temperatures as it is hidden from the sun (Figure 8. While others (Pelkey et al., 20003) have noted this strong effect, they utilize the visible images for understanding the geomorphology on a local scale. In the THEMIS day time visible images of Elysium Mons, features such as faults, grabens, outflow channels, impact crater, impact ejecta, pit crater chains, and the large fossae can be seen and investigated. At night, the temperatures and values of the IR images are primarily a function of the thermal inertia of the surface. Exposed bedrock along the walls of fossae and pits can be seen with higher surface temperatures. Interpretation of thermal inertia anomalies can be difficult as thermal inertia changes due to a multitude of factors such as particle size and bedrock exposure.

Also in the visible images, exposed rock units can be seen along the canyon walls of the large fossae (Figure 8). While as many as four rock units can be seen in the visible image, the rock units could not detected in the IR image.
While it is unclear if enough difference in thermophysical properties exists between rock units to make them detectable, the spatial resolution of the IR images is clearly inadequate to detect these particular units.

While the thermal signature of the surface rocks is obscured by atmospheric and surface dust, gross thermal signatures from THEMIS thermal images can be used to distinguish geomorphologic features. In this project, we reviewed published THEMIS results and learned how to acquire and process the THEMIS data. We were also able to use the IR and visible images to perform a general investigation of on Elysium Mons.
Figure 4: An initial investigation using visible and thermal THEMIS images was performed on the northwest slope of Elysium Mons. Four areas are discussed in the text and in Figure 5-8.
Figure 5: The northwestern flank of Elysium Mons as shown in (a) MOLA topography, (b) THEMIS visible image V06299019, and (c) nighttime IR image I07404019 displays a series of faults and a coalesced pit chain. Red indicates higher elevations while blue indicates lower elevations. Lights colors indicate higher surface temperatures. Northwest facing slopes along fault scarps and pit chain walls have higher temperatures. Deposits from outflow channel have an elevated temperature from the surrounding surface.
Figure 6: The northwestern flank of Elysium Mons as shown in MOLA topography (a), THEMIS visible image V05912011 (b), and daytime IR image I02167007 (c) display two crossing grabens. A pit chain extends in the center of the image from the NW oriented graben to the end of the SE oriented graben. Smaller faults and numerous impact craters are seen in the two THEMIS images. The sun facing western and northwestern slopes along fault scarps and pit chain walls have higher temperatures.
Figure 7: Large canyon wall of a deep fossae on the northwestern flank of Elysium Mons as shown in a nighttime IR image I07404019 (a) and a THEMIS visible image VV06299019 (b). The large fossae wall faces the south west. Red colors in IR image indicate higher surface temperatures which at night is primarily a function of thermal inertia of the surface. Rocks with higher surface temperature are exposed along the fossae wall and on the sides of the pits.
Figure 8: A narrow deep graben and the southern edge of a deep fossae on the northwestern flank of Elysium Mons as shown in THEMIS daytime IR image I02167007 (a) and visible image V05912011 (b). Red colors in IR image indicate higher surface temperatures. Slopes facing the solar illumination are extremely bright in visible image and red in IR image. Different rock layers are exposed along the canyon walls of the fossae. Individual layers can not be detected in the IR image.
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