THERMAL INFRARED REMOTE SENSING OF TERRESTRIAL IMPACT CRATERS AS ANALOGS FOR MARS S.P. Wright[1] and M.S. Ramsey[2], [1]Department of Geological Sciences, Arizona State University, Tempe, AZ 85287-1404, [2]Department of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260, Shawn.P.Wright@asu.edu, ramsey@ivis.eps.pitt.edu

Introduction: Thermal infrared (TIR) remote sensing has contributed to our knowledge of Earth [1] and Mars [2,3]. However, remote sensing has its limits. A thorough knowledge of thermal emission physics and the effects of the TIR instrument's spatial and spectral resolution are needed for accurate interpretation of TIR data. Current TIR instruments orbiting each planet offer a unique opportunity for comparative studies. The Thermal Emission Imaging System (THEMIS) has the capability to map small regions of impact craters such as ejecta blocks, inner crater walls, and windstreaks. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) has a comparable spatial and spectral resolution over the visual and near infrared (collectively, VNIR) and TIR wavelength regions and can be used as a proxy to test spectral analysis models [4]. Further, field observations, field TIR spectrometers, and high-resolution airborne TIR data provide means to study terrestrial impacts and validate spaceborne TIR data.

To date, the authors' terrestrial TIR studies of impact craters have focused on Meteor Crater, Arizona, but other impact sites are being considered for their composition and/or preservation. Clearly, Mars does not have the mineralogic and lithologic variability of Earth [5], and the target rocks at Meteor Crater are an example of this. However, the methodology of determining the physical nature and distribution of ejecta by TIR and VNIR remote sensing should be identical. Additionally, ground truth validation at terrestrial impact sites provides insight into crater properties such the distribution of ejecta, rim uplift, and the location of impact melts.

TIR remote sensing: The focus of the TIR is due to the fact that most major rock-forming minerals have significant absorption features in this region [6]. Further, TIR data have been shown to add linearly and thus be easily interpretable [7]. The composition and aerial abundance of each lithology can be calculated due to the fact that the emissivity spectrum from a surface is a combination of the emissivities from each component in proportion to its aerial percentage [7]. However, small particles sizes (< 60 µm) [7] and significantly thick dust coatings can effect the interpretation of TIR spectroscopy [8].

Application to Mars: According to size versus frequency diagrams, non-degraded, small impact craters outnumber large craters on unmodified planetary surfaces and are of younger age [9]. Younger impact craters will have less erosion and denudation, a well-preserved ejecta blanket, and less dust at the surface, making them excellent sites for TIR observations of the surface composition. The uplifting of bedrock in rims and the presence of rocky ejecta blankets in high-albedo regions is of interest. Of further interest is being able to identify the inner-crater stratigraphy and the distribution of those units in the ejecta blanket in order to infer the geology and local climatic conditions of the region before and after crater formation.

Instrumentation: ASTER is a multispectral imager on the Terra spacecraft and is part of NASA's Earth Observing System. ASTER has fourteen bands from the visible to the thermal wavelengths, including five in the TIR at 90 meter spatial resolution and three bands in the VNIR at 15 meter spatial resolution [10]. It has been operational since December, 1999 and has collected seven images of Meteor Crater, Arizona.

THEMIS, a multispectral imager on the Mars Odyssey orbiter, has returned images in the VNIR and TIR wavelengths since February 2002. The primary objectives and science goals of THEMIS are to determine the mineralogy and petrology of the surface of Mars utilizing the hyperspectral data of the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) to study small-scale geologic processes and potential future landing sites [3]. THEMIS has ten TIR bands from 6.5 µm to 15.5 µm. The defining attribute of THEMIS is a spatial resolution of ~100 m. This represents the highest spatial resolution to date of Mars over the TIR wavelengths. Precise details of small (< 2 km) impact sites were not possible prior to THEMIS. THEMIS also has five bands in the VNIR at 18 meter spatial resolution. These data can be co-registered ("layered") with TIR data to provide insight into the composition and thermophysical properties of ejecta blocks, rim uplifts, inner-crater stratigraphy, and eolian deposits.

Meteor Crater, Arizona: Meteor Crater is located in semi-arid, north-central Arizona and is estimated to be 50,000 years old, making it one of the most recent and well-preserved impact sites on Earth [11]. The simple, bowl-shaped crater is 180 meters deep and 1.2 km in diameter with an eroded rim standing 30-60 m high. The local geology consists of three flat-lying sedimentary members with well-documented lithologies and contrasting spectral signatures. The oldest unit sampled by impact is the Permian Coconino Sandstone. Above the Coconino are the Permian Kaibab Limestone and a thin veneer of the Triassic Moenkopi Formation. The crater ejecta consists of the same lithologies as above, but inverted due to impact. Minimal vegetation make the crater an ideal location for TIR remote sensing.

Previous Work: The authors have investigated the distribution of ejecta at Meteor Crater, Arizona using various TIR instruments [12,13] and applied similar methodologies to Mars [14,15]. *Ramsey* [12] used TIR data from the high-resolution Thermal Infrared Multispectral Scanner (TIMS) to map the lithologies distributed in the ejecta blanket (Figure 1A) and calculate estimates of ejecta erosion. The latter was performed by estimating the current volume of Coconino Sandstone ejecta and comparing this to theoretical values of the amount ejected on impact. The amount of erosion agreed with earlier estimates of 1-2 m by *Grant and Schultz* [16]. *Wright and Ramsey* [13,14,15] incorporated ASTER TIR data into the study to simulate the interpretation of THEMIS TIR data of similar-sized craters on Mars (Figure 1B). It was found that areal abundance of image end-members selected by cluster analysis agreed with the high-resolution TIMS data to within 10% (Figure 1). This mapping approach fails where lithologies with small areal percentages and/or similar TIR spectral signatures are present. Due to resolution degradation, the areal extent of windstreaks and certain lithologies may be increased by as much as 10%. This methodology was applied to THEMIS TIR data of a similar-sized impact site in Syrtis Major [14,15]. Temperature images of the crater are shown here (Figure 2).

Future Work: It is possible that one or both of the Mars Exploration Rovers (MER) will sample an impact crater ejecta blanket. Because the two MERs each have a Mini-TES instrument, studies concerning field TIR spectroscopy, TIR spectra of shocked basalt, and compositional analogs are being proposed.

The Micro Fourier Transform Interferometer (μFTIR) instrument represents one of a very small number of field TIR spectrometers [17] and will be used at Meteor Crater before the end of 2003. This has applications to data from the Mini-TES instrument [18] in which a proxy TIR instrument was not constructed for Field Integrated Development and Operations (FIDO) prototype Mars rover field trials [19].

Lonar Crater, India is one of just two terrestrial impacts (of ~180 known) that is emplaced in basalt [20]. Previous studies have identified Deccan basalt as an excellent Mars analog [21,22]. Further, it has been shown that naturally-shocked Lonar basalt had different petrographic properties than experimentally-shocked Deccan basalt [23], and this may affect the TIR spectra. It has been shown that TIR absorption features of certain minerals are effected by the degree of shock metamorphism [24]. In that study, experimentally-shocked minerals were used. Sample emission spectra of naturally-shocked Lonar basalts may prove useful to the interpretation of TIR data from instruments on the surface of or orbiting Mars.

Conclusions: The study of terrestrial impact craters via TIR remote sensing has many applications to Mars. Analyses of terrestrial impact sites and their associated samples provide insight into the interpretation of TIR data from Mars. These investigations plus future field and remote studies should better constrain the primary objectives of the THEMIS instrument and add to our knowledge of martian impact structures.

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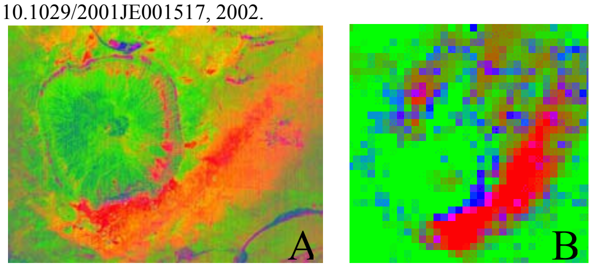

Figure 1: TIMS and ASTER image end-member analyses

Whereas TIMS data has a 3.2 m spatial resolution, the resolution of ASTER is 90 m. This is comparable to THEMIS TIR. In both images, R = Coconino Ss, G = Kaibab Form., B = Moenkopi Form., and north is up.

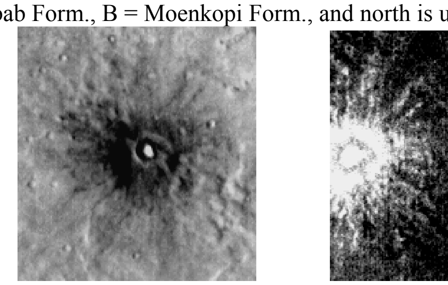

Figure 2: Day and Night THEMIS temperature scenes

The two scenes do not cover the same area of a 1.0 km diameter crater in Syrtis Major (4° S, 59° E). The ejecta has a lower temperature than the surrounding plain during the day (260 K – 274 K) and a higher temperature at night (190 K – 177 K), indicating a higher thermal inertia and a larger particle size.