Remote Sensing of the Haughton impact structure (HIS): A terrestrial proof of concept for using the remote sensing of martian craters as a probe of subsurface composition. L. L. Tornabene[1], G. R. Osinski[2], J. E. Moersch[1], and P. Lee[3], [1]Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 [3]Mars Institute, SETI Institute & NASA Ames Research Center, Moffett Field, CA 94035.

Introduction: Impact cratering is the most widespread geological process in the Solar System. Impact craters can provide "windows" into the subsurfaces of planetary bodies through excavation and uplift. By utilizing remote methods in the visible and near infrared (VNIR; 0.4-1.4µm), short-wavelength infrared (SWIR; 1.4-2.5µm) and thermal infrared (TIR 7-14µm), subsurface mineral compositions may be identified and mapped via impact craters. Complex craters in particular, expose minerals from both the shallow and deep-seated subsurface, which may be identified spectroscopically. Complex craters have morphological features such as central peaks or peak rings, which are composed of relatively coherent lithologies tapped from deep-seated crustal components [1]. While near-surface crustal components can be observed as coherent rocks uplifted and exposed in the rim and the crater walls, and from the ejecta deposits [2-3].

Only two previously published studies using this approach have been successful on large planetary bodies. Tompkins and Pieters [2] utilized ultraviolet and VNIR from Clementine to characterize near- and deep-subsurface materials in and around lunar craters. The work of Ramsey and Wright [3,4] was the first remote spectroscopic study to successfully identify near-subsurface materials in the ejecta and crater wall of a terrestrial impact structure, namely Meteor Crater. Here we present early results of a third such study, a remote spectroscopy evaluation of the Haughton impact structure (HIS).

The purpose of this study is to serve as terrestrial proof of concept that remote visible/infrared spectroscopic methods—in this case, analysis of LANDSAT 7 ETM+ and ASTER data of the well-preserved HIS—can be utilized in deciphering the subsurface composition of planetary crusts. This technique is particularly promising for Mars were limited tectonic uplift and ubiquitous dust-mantling offer few opportunities to access subsurface information.

Geologic Setting: The HIS is a well-exposed and well-preserved complex crater centered at 75°22'N, 89°41'W on the western end of Devon Island, in the Canadian Arctic Archipelago, Nunavut Territory. The maximum diameter of 24 km is based on seismic reflection studies, and the oldest estimated age of 23.4 ± 1.0 Ma was derived from ^{40}Ar-^{39}Ar analysis of strongly shocked basement rocks [6, 7]. Originally mapped as a salt dome by Greiner in the 1950's, HIS was later proposed to be an impact structure by Dence, and subsequently it was recognized as such based on shatter cones described by Robertson and Mason and the discovery of coesite by Frisch and Thorsteinsson [8-14].

The HIS target rocks consist primarily of a sequence of gently westward-dipping dolomites and limestones with subordinate shales, evaporites and sandstones that strike approximately N-S [12, 13]. These units are contained within a ~1880 m conformable Lower Paleozoic sequence (Cambrian to Siluro-Devonian in age) that unconformably overlies the granitic gneisses of the metamorphic basement complex [14]. The target rocks in the environs of the HIS consist mainly of dolomites and limestones of the Ordovician-Silurian Middle and Lower Members of the Allen Bay Formation, respectively. However, exposures of older Ordovician units outcrop to the east of the structure and as fault blocks within the structure itself, such as the gypsum- and anhydrite-bearing Bay Fiord formation along with minor amounts of shale from the Irene Bay formation [12-14]. The underlying chert-bearing Eleanor River Formation outcrops as central uplifted material that projects up through the impact-melt breccias, and also within the inner topographic ring surrounding the impact-melt breccia of the crater moat [12].

The crater fill deposits within the HIS consist of a melt-matrix breccia unit and the post-impact lake deposits of the Haughton Formation, as well as small amounts of Quaternary alluvium. The melt-matrix breccia contains >90% dolomitic clasts with lesser amounts of limestone, shale, sandstone, gypsum and gneissic fragments enclosed in a matrix of silicate glass and shock-melted carbonate[13]. The Haughton Fm. contains varved lake sediments consisting of limy sands, silts and mud [15].

Methods: Scenes from both the LANDSAT 7 Enhanced Thematic Mapper plus (ETM+) [16] (scene LE7040007000021150) and Terra Airborne Space Thermal Emission Radiometer (ASTER) [17] (scene SC:AST_L1B:003.2017172817) instruments were utilized for spectral analysis of the HIS. Both scenes were processed by band ratioing single-band images, decorrelation stretching and principle component (PC) analysis to 1) remotely map the HIS, and 2) spectrally correlate uplifted and exposed units within the crater to the undisturbed target sequence in the surrounding terrain. Uplifted units within the HIS can be easily correlated with older units in the gently dipping sequence stratigraphy of Devon Island, with undisturbed older stratigraphic units outcropping east of the HIS.

Results/Discussion: Specific units were identified in the processed ETM+ and ASTER scenes that can be directly correlated with lithologies from depth (i.e. further down the undisturbed target sequence). Fig. 1 shows a decorrelation stretch of the ASTER TIR image as an example, although other types of processed images from both ASTER and ETM+ showed similar spatial correlations. ASTER's similar wavelength coverage and spatial resolution to THEMIS makes it an excellent proxy for conducting a similar study on Mars [3-5].

Three spectral units interpreted to be exposed subsurface are identified in Figure 1C and 1D. Unit 1 (lime-green pixels mottled with yellow and light blue) maps as a contiguous area near, or on the crater wall. Based on field observations, Unit 1 correlates with limestone of either the Lower Member of the Allen Bay Fm., or the Thumb Mtn. Fm, which has a pre-impact depth of 500 and 700 meters respectively (Figure 1A) [18,19]. Unit 1 is interpreted to be exposed wall rock and slumped terrace blocks, which represents relatively shallow-subsurface in impact craters. Unit 2 maps as bright red gypsum-rich layers and outcrops as part of the melt-matrix breccia unit. The gypsum of Unit 2 unequivocally represents the Bay Fiord Fm, which lies almost 1000 meters beneath the pre-impact surface [19]. Unit 3 consists mainly of lime-green pixels, and is interpreted to be uplifted Eleanor River Fm. based on field studies and its occurrence in the central uplift [12, 18, and 19]. The pre-impact depth of the Eleanor River Fm. is just short of 1100 meters; this agrees well with the previous scaling estimates for the pre-impact depth of central uplift materials for a crater the size of HIS [7].

Conclusions: The HIS is unique and ideal for this study because of its lack of vegetation, exposure, and preservation state. These qualities facilitate a lithologic assessment of the HIS via remote sensing. Even more importantly, the undisturbed target sequence at the HIS is slightly tilted and exposed, so that lithologies from further down the stratigraphic sequence are exposed east of the structure. This enables us to directly compare units excavated by the crater with units of the undisturbed target sequence.

To our knowledge, this is the first study in which a central uplift in a terrestrial impact structure has been identified by spectral methods to expose deep-subsurface lithologies. Our work at the HIS suggests that similar analyses of data from THEMIS and other vis/IR remote sensing experiments at Mars may be successful in determining subsurface compositions, provided that exposures at the surface are not mantled by obscuring dust.

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