AN UPDATED ORBITAL ANALYSIS OF ANCIENT STRATA IN TERBY CRATER, MARS: THE THICKEST DELTAIC SEQUENCE ON MARS?

C. J.-K. Yen[1], R. E. Milliken[1], A. A. Fraeman[2], Y. Itoh[3], M. Parente[3], J. L. Dickson[4], [1]Dept. Earth, Env. and Planetary Sciences, Brown University (christopher_yen@brown.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, [3]University of Massachusetts Amherst, [4]California Institute of Technology

Introduction: Terby crater is a ~174 km diameter impact crater on Mars that superposes part of the northern rim of the ancient Hellas impact basin. Its interior morphology includes a flat floor and several tall mesas composed of visibly stratified deposits. The geometry of these strata has previously been interpreted as evidence that they represent ancient deltaic deposits or sediment emplaced in a sub-aqueous environment [1]. If correct, the deposits in Terby may represent one of the largest and thickest deltaic sequences observed on Mars, possibly thicker than deltaic strata encountered in Gale crater by the Curiosity rover [2]. The volume of deposited sediment has been estimated to be >5000 km^3 and may have been up to 2.5 km in thickness. In addition, Terby crater is believed to have formed in the Early Noachian epoch (~4.0 Ga), and thus thick deposits preserved in Terby may record geologic and climatic processes that occurred since this time during all three geologic periods of Mars (Noachian, >3.5 Ga; Hesperian, ~3.5-2.6 Ga; Amazonian, <2.6 Ga). Major processes that occurred on Mars during this time may include widespread clay formation in the Noachian, increased oxidation and possible acidification of the surface environment and enhanced aeolian erosion during the Hesperian, and a shift to cold, hyperarid conditions in the Amazonian [e.g., 3].

Ansan et al. (2011) performed extensive stratigraphic mapping of layered deposits in Terby using orbital visible images acquired by instruments such as HRSC (High Resolution Stereo Camera) and HiRISE (High Resolution Science Imaging Experiment). Those authors also conducted an initial mineralogical assessment using thermal infrared data and visible-near infrared reflectance data from the CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) instrument. However, a significant amount of new CRISM data have been acquired since that study, and these data have not yet been fully evaluated to further test the deltaic hypothesis discussed in [1]. In addition, that study relied on ~50 m/pixel digital terrain models (DTMs) derived from HRSC data, yet a number of newer HiRISE images can be used to generate DTMs with a spatial scale of 1 m/pixel. This order of magnitude improvement in spatial scale can provide new information about the geometry of strata in Terby, a necessary step to better assess a possible deltaic origin [e.g., 4]. Previous analysis of deposits in Terby relied on two CRISM scenes that spanned a small portion of the preserved mounds. Additional work is warranted to fully map the mineralogy of these deposits and determine if compositional variations, in addition to the stratigraphic architecture, is consistent with a deltaic origin or if other modes of deposition may be present. In addition, the newer CRISM data allow for a more comprehensive assessment as to whether or not mineralogical boundaries conform to stratigraphic boundaries, an important step in constraining depositional versus diagenetic origins for hydrous minerals observed from orbit.

Methods: We performed a systematic analysis of all available high-resolution (i.e., ~18-36 m/pixel FRT, FRS, and HRL) CRISM scenes that cover Terby Crater. To date, a total of 15 CRISM scenes were processed using a method [5] to minimize atmospheric and noise effects that are common in CRISM spectral data. These newly processed images allow for more robust detection and identification of weak mineral signatures and reduce the need to use spectral ratios to identify regions of interest.

Interesting spectral features observed in the CRISM data were compared with laboratory spectra of different minerals to determine the composition of sediments in Terby. Maps of various spectral parameters (e.g. strength of absorption features) [6] were used to detect characteristic absorptions of different minerals in the CRISM data and map-projected versions were integrated into a GIS framework for comparison with visible CTX and HiRISE images. Detections from spectral parameter maps were manually verified to minimize risk of false positive detections.

A morphologic map was constructed in GIS using a CTX mosaic as the basemap, with the goal of outlining major morphologic units within and adjacent to the mesas. We also examined HiRISE images that overlapped with CRISM scenes to inspect stratigraphic relationships and outcrop geometry for regions exhibiting hydrous minerals. Ongoing work is focused on constructing 1 m HiRISE DTMs to measure strike and dip [e.g., 7] throughout the exposed stratigraphic section to better identify possible deltaic foresets and other changes in bedding geometry.

Results: The dominant morphologic units include light-toned bedrock, moderate-toned cover units that appear to be partially lithified, and unconsolidated materials (including dunes). The light-toned bedrock that dominates the mesas in Terby varies in thickness, ranging from relatively thin (meters-thick) to massive (tens of meters or more), similar to results of [1]. HiRISE images

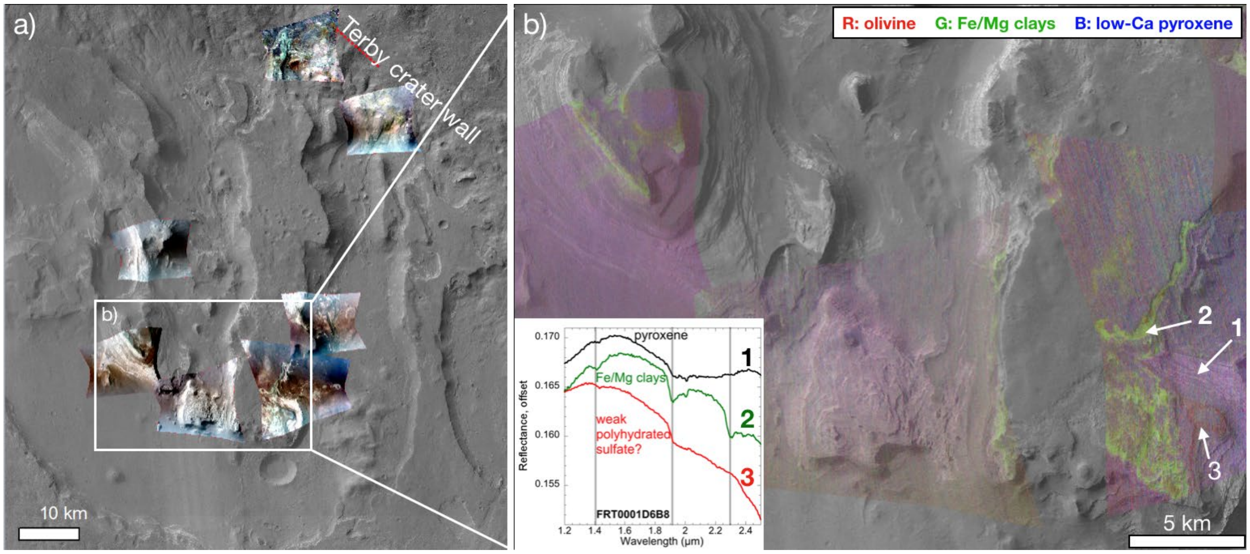

Figure 1. a) Overview map (CTX mosaic) of NE Terby crater showing mesas of potential deltaic origin overlain by several false-color CRISM images. b) CRISM clay 'map'(green tones) of southern portions of mesas showing pyroxene and lack of hydrous minerals in bulk of strata (spectrum 1) but clear increase in clay signatures in uppermost units (spectrum 2).

are now being used to map the bedding of the westernmost mesa at a finer scale in order to construct a detailed stratigraphic column and provide estimates of bed thickness.

CRISM data reveal that clay minerals are observed in numerous regions of the mesas, portions of the crater wall, and in a crater that superposes the rim of Terby (Fig. 1). The spectral signatures vary with location and exhibit diagnostic 1.4, 1.9, and 2.29-2.35 µm absorptions that are consistent with Fe/Mg clay minerals. Some spectra exhibit a broader and asymmetric 2.3 µm absorption that may indicate chlorite or mixed-layer chlorite/smectite rather than pure smectite. There is at least one instance of a small exposure of hydrated silica. Though not as common, spectra in some regions exhibit a strong 1.9 µm band and a drop in reflectance at wavelengths >2.4 µm, characteristics that are consistent with the presence of polyhydrated sulfates (Fig. 1b inset). Finally, locations in several CRISM images exhibit spectra with absorption features at 2.3 and 2.5 µm that may be indicative of carbonate minerals [e.g., 8]; analysis of these regions is ongoing in order to confirm this initial interpretation.

Discussion: Clay minerals are much more widespread in Terby crater than previously recognized, which taken at face value may indicate the presence of finer-grained sediments (e.g., mudstones) consistent with deposition in a quiet setting such as a lake [e.g., 1]. However, the clay signatures are commonly found in the uppermost strata of the mounds that correspond to thicker or more massively bedded regions that appear slightly darker-toned in HiRISE images. In contrast, outcrops of the underlying lighter-toned and thinner bedded units that make up the bulk of the mesas often exhibit pyroxene signatures but tend to lack clear evidence for hydrated minerals (Fig. 1), though there are some exceptions.

If the bulk of the strata within the mesas represent deltaic sediments then they appear to be relatively poor in clay minerals and other hydrous phases. This could be because they are dominated by coarser facies (e.g., sandstones) composed primarily of unaltered igneous minerals with an unknown cementing agent. Alternatively, fine-grained facies could be present throughout the mesas but be thin compared to CRISM resolution or be dominated by unaltered basaltic components due to short transport distance or limited interaction with water.

Ongoing analysis is focused on understanding the relationship between the boundaries of clay-bearing zones seen in CRISM data and stratigraphic boundaries mapped at HiRISE scale to determine if the clay-bearing zones conform to or cut across bedding. There is currently no clear indication that the clay-rich zones correspond to potential deltaic bottomsets. Because clays within the different mesas occur at similar stratigraphic positions, near the top, it cannot be ruled out that they represent the weathering profile of an ancient paleosurface exposed to climatic conditions that were distinct from those under which the majority of the mesa sediments were deposited.

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