CRATER-EXPOSED INTACT STRATIGRAPHY BLOCKS AND VOLCANOGENIC ORIGIN.
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Introduction: Exposures of stratigraphy viewable from orbit are rare on Mars, which presents a challenge for studying the geologic history. Stratigraphy is typically reconstructed through geologic mapping using superposition relationships and crater counts of surface material [1,2]. This study uniquely exploits crater formation mechanisms to study underlying blocks of bedrock, which are uplifted from estimable depths and strongly tilted in the central uplifts of craters, making these exposures ideal for orbital remote sensing studies of upper crust stratigraphy. Here we use a variety of Martian datasets to identify (THEMIS IR, MOLA) and classify (CTX and HiRISE) crater-exposed bedrock exposures, revealing three distinct classifications of bedrock textures [3]. Of the 912 craters surveyed, 222 have bedrock that is sufficiently exposed and extensive enough to classify their morphologies. The focus of this study is Intact layered Stratigraphy (IS) (i.e., uplifted and inverted bedrock consisting of strongly layered and intact blocks of stratigraphy with layers ranging from meter to decameter scales in HiRISE images).

As seen in Figure 1, a strong correlation exists between the location of the 41 IS craters observed and the major volcanic provinces and mapped Hesperian flood lavas and ridged plains (purple units), generally interpreted as flood lavas [1,4]. Based on this strong correlation, dominant mineralogies consistent with mafic volcanics, and morphologic similarity to layers exposed in Valles Marineris [9], we interpret the IS as strong layers of lava interleaved with weaker deposits such as pyroclastics, regolith, or other sediments.

Here we couple the geologic context and textures observed from depth with the measurable thickness and cyclicity of the IS layers, which alternate between competent and less competent layers within a given uplifted megablock, to better understand and relate past geologic events and processes across vast regions of Mars. Along with our sister study [3], the two additional bedrock textures that we have identified include Fractured Bedrock (FB), a light-toned and massive textured material that is possibly plutonic in origin, and MegaBreccia (MB), interpreted to be a re-sampling of crust previously brecciated from a period of heavy bombardment (through careful examination of crater morphology in this study, MB bedrock is differentiated from brecciated material that is surficially emplaced consequent of the exposing crater).

Depth measurements: We measure and compare the estimated depths of these bedrock blocks based on crater scaling estimates which allows for inferences regarding the geologic history of provinces. Applying crater scaling relationships to complex IS craters (ranging from ~10 to 125 km diameter) provides a unique opportunity to place constraints on the extent and kilometer-scale thicknesses of IS bedrock in these provinces.

During formation of complex craters, bedrock is brought to the surface from depth in central uplifts [5]. The estimate for stratigraphic uplift (SU) used here is $SU=0.086D^{1.03}$, where D is the final rim diameter [6,7]. The SU value for a given crater is subtracted from the average elevation of the crater central uplift (gridded 128 ppd MOLA data) to derive an estimate of the depth of sampling. We have evaluated bedrock depths for crater central uplifts globally and compared them on a regional basis to assess the upper and lower limits of observed bedrock units. Such assessments include depth and geographic boundaries for interpreted volcanics defined by craters in Bosphorous Planum, at the transition between the mapped Hesperian-aged flows [2] south of Valles Marineris and heavily cratered Noachis Terra to the east. Fractured Bedrock (FB) is observed and estimated to originate from depths of -8807.0m (D=79.1km, -29°S, 309°E) to -1871.25m (D=28.3km, -20°S, 307°E), while Megabreccia (MB) is estimated to originate from -1549.0m (D=22.2km, -36°S, 302°E), possibly marking the southern geographic extent of the flow in this narrow region. IS being re-sampled in crater central peaks between depths of -1454.5m (D=18.7km, -29°S, 305°E) and -1092.0m (D=15.4km, -30°S, 304°E). These estimates indicate a possible regional stratigraphy that consists of massive-textured bedrock, possibly plutonic, at greater stratigraphic depths represented by FB and overlain by MB (suggesting previously and heavily cratered terrain being re-sampled from intermediate depths). The shallowest unit is represented by the IS blocks, possibly reflected in the distinctive wrinkle-ridge plains morphology on the surface, and is interpreted to be largely volcanogenic materials.

Bedding cyclicity and thickness measurements: The cyclic nature of the IS is clearly recognizable as alternating higher-standing and lower-standing layers which is observed throughout the stratigraphic column of the intact block. The apparent differences in height are suggested to be a function of the difference in competency of the materials and their relative resistance to erosion post-exposure. An elevation profile is drawn across and perpendicular to the layers (displayed graphically in Figure 2B), allowing a line to be fitted to the higher-standing competent layers. The lower-standing layers, which are interpreted to have experienced more erosion, deviate from the line a measureable distance denoted here as the erosional differential. Preliminary results from Martin Crater (D=58.5km, -21°S, 290°E) indicate that individual layers with bedding orientations measured at a dip of ~45° [11] have an erosion differential of 7.39m. These measurements taken for an unnamed crater ~400km NE of Martin have an average erosional differential of 7.74m. Measurements for these two craters match closely which, coupled with regional context and similar stratigraphic uplift estimates, suggests similar layer lithologies and possibly common origins for the layered materials sampled in both craters. Measurement of this erosional differential is one way that we can relate the lithologies of layers over a region as well as globally.

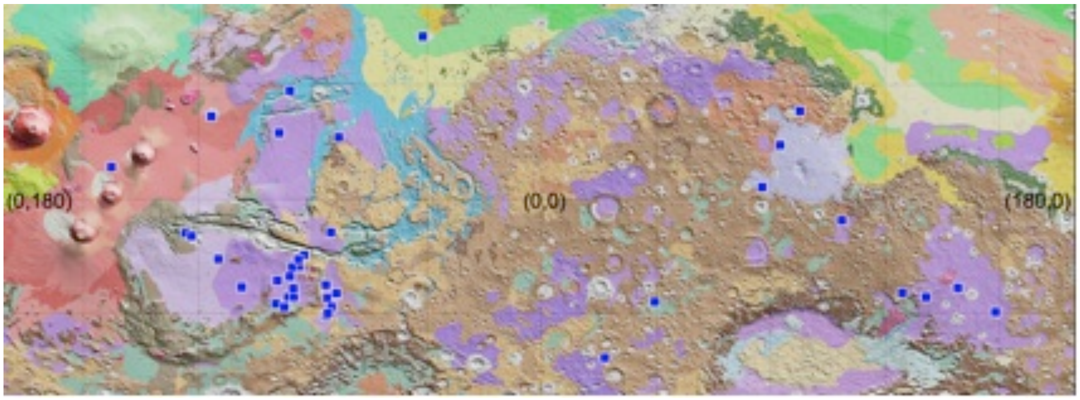

Figure 1. Global (±50° latitude) distribution of crater central uplifts displaying the re-sampled layered material, shown in blue, overlain onto a geologic map [2]. Purple units are Hesperian ridged plains and reddish units are Amazonian volcanics.

Individual bedding thickness of these tilted IS blocks provides another means of determining if the layers may be of similar or differing origin within and across regions. In this study, we derive bedding orientations and thicknesses by mapping the individual layers with Socet Set spatial analyst software yielding 3-D spatial information imbedded in HiRISE image stereo pairs. With known bedding orientations, we then derive true bedding thicknesses of layers which may speak to lithologic origins and quantities such as volume of lava and pyroclastics or other sediments that may have created the layers spanning any given region.

Spectral signature comparisons: In addition to morphologic and morphometric analyses, we are currently undertaking spectral analyses with CRISM to determine mineral and lithologic compositions to further constrain of the origin and relationships of layers over broad areas. Using the CRISM spectral summary products, we have begun to assess spectral properties of crater central uplifts where CRISM is available and obscuration by dust is low. We have found that a global distribution of crater central peaks with IS morphology are likely to possess varying concentrations of specific mineral signatures including olivine, Low Calcium Pyroxenes (LCP), High Calcium Pyroxenes (HCP), and Fe/Mg phyllosilicates. Similar mineral signatures have been previously observed in Coprates Chasma walls from the uppermost layers to depths of -4000m [8], which are consistent with the sampling depths of to the stratigraphic uplifts of regional craters exposing IS-textured bedrock (crater sampling depth estimates range from -622m to -4863m). TES spectral analysis suggests similar mineral compositions within the competent wall layers of Ganges Chasma competent wall layers, where emplacement has been interpreted as an olivine-rich basaltic lava flow [9]. Circum-Hellas exposures interpreted to be volcanogenic are shown through OMEGA spectral analysis to also have mineral signatures similar to IS bedrock including olivine, LCP, and HCP [10].

Conclusions: The IS unit in the central uplifts of 41 craters is strongly correlated with terrains previously mapped as volcanic. Mineralogies are also consistent with predominantly volcanic lithologies. The IS stack ranges from 0.6 to 4.9 km thickness in Bosphorus Planum, with additional regional stratigraphic stacks to be analyzed and presented, providing quantitative information on the volcanic and geologic history of Mars.

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