METER- TO DECAMETER-SCALE CHARACTERISTICS OF CENTRAL UPLIFTS REVEALED BY THE MARS RECONNAISSANCE ORBITER. L.L. Tornabene[1,2] , G.R. Osinski[1,3], N.G. Barlow[4], V.J. Bray[5], C.M. Caudill[1], B. D'Aoust[1], N. Ding[5], R. Hopkins[1,3], A.M. Nuhn[1], A. Mayne[4] and A.S. McEwen[5]. [1]Dept. of Earth Sciences & Centre for Planetary Science and Exploration, University of Western Ontario, London, ON, N6A 5B7, Canada (livio@cpsx.uwo.ca), [2]SETI Institute, Mountain View, CA 94043, USA, [3]Dept. Physics & Astronomy, Western University, London, ON, N6A 5B7, Canada, [4] Dept. Physics and Astronomy, Northern Arizona Univ., Flagstaff, AZ 86011, USA, [5]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA.

Introduction: Ongoing orbital observations of Mars continue to reveal the morphologic, spectral and structural complexity and diversity of crater central uplifts (CUs). High-resolution sub-meter (~25 cm/pixel) images from the High Resolution Imaging Science Experiment (HiRISE) combined with decameter-scale images from the Context Camera and hyperspectral information the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) onboard the Mars Reconnaisance Orbiter (MRO) [1-3] are providing unprecedented and remarkably preserved geologic detail of surface features associated with CUs [4-19]. Observations elucidating various aspects of the impact process, particularly with respect to the occurance and emplacement of various impactites, and the structures associated with central uplifts (CUs) in complex craters are summarized here.

Background: *Geology of terrestrial CUs.* Impactite classification is mainly tied to the provenance of the pre-existing target rocks of which they are comprised. As such, they are divided into two basic groups: allochthonous (A-type) and parautochthonous (P-type) [see 20]. The term allochthonous refers to a rock typically formed from multiple rock types, and/or non-local source(s). A-type impactites include impact melt-bearing rocks, which can either include or exclude rock mineral or lithic fragments or clasts. "Suevite" refers to a specific breccia type that was first characterized at the Ries impact structure, Germany [see 8]; this lithology essentially consists of melt clasts enclosed within a fine-grained matrix. The A-type class also includes clastic supported melt-poor "lithic" breccias. P-type rocks generally refer to pre-existing target rocks that are shifted "slightly" out of their place of origin (i.e., uplifted and displaced rocks). Importantly, A-type rocks both superimpose (e.g., coatings, flows and ponds) and intrude (e.g., dykes) into P-type rocks. These morphologic and stratigraphic relationships are key and are sought here to properly identify impactites to the best of our ability in exclusively orbital images.

General Methods: We are compiling a global crater-exposed bedrock (CEB) database (DB) for Mars from a survey of 1684 complex craters and using data that is primarily derived from MRO instruments. The current CEB DB consists of 200 entries spanning ~60˚N to 50˚S, which are primarily based on morphologic observations based off of HiRISE images, but also include CTX, CRISM and other Mars datasets when available (e.g., DTMs, thermal inertia, etc.).

Observations: *Volatile-rich impact-melt bearing deposits***.** Here below is a summary of observations of Martian crater-related pitted materials (CRPM) from [21], which supports the interpretation that they are most consistent with volatile-rich impact-melt bearing deposits. To date, we have observed CRPM in 238 of the best-preserved impact craters on Mars [21-22] (CRPM is also observed on the airless body Vesta [23]). CRPM-bearing Martian craters span ~1–150 km in diameter and from 53°S to 62°N with the majority occurring ~10–30° N and S. There are fewer to a complete lack of these craters at or near the equator and high latitude, respectively. The pits are distinctive depressions with circular to polygonal shapes. Pits possess subtle topographic rims with no signs of apparent proximal ejecta materials. Pit size shows a clear relationship to their host deposits and crater diameter.

CRPM occurs in a similar crater-setting as impact melt-rich flows and deposits associated with well-preserved lunar craters. This includes as part of the crater-fill deposits, and as ponds, flows and coatings on CUs, terraces and crater ejecta. Non-dusty and well-exposed sections of the CRPM show that they consist of lighter-toned decameter-sized clasts enclosed in a darker-toned matrix. These and other CRPM observations (see [21-23]) are generally consistent with impactites, likely consisting of a mixture of impact melt, and both mineral and lithic fragments. The pits are considered to be the result of interactions between hot, highly shocked materials with volatile-rich phases or water-ice derived directly from the target materials (likely as entrained clasts or where in contact with P-type rocks). Volatilization of water within the deposit leads to rapid, and perhaps explosive, degassing with pits corresponding to locations of degassing pipes.

Surface features exposed in Martian central uplifts. A-type units. All Martain CUs in our database exhibit the occurrence of a widespread (generally ~25-90%) relatively smooth and rigid dark-toned unit that is often observed grading from a clast-poor to clast-rich facies and are interpreted as impact breccias. We note here that it is difficult, if not imppossible, to ascertain whether the matrix of a breccia deposit is melt/glass-or clast-rich; however, many of these units are interpreted to be impact melt-bearing units based on their textures and morphologies [e.g., 4-6, 8]. For example, this unit is often observed as a contiguous unit that extends from the summit of the CU to the crater floor and ranges from high to low slopes. This unit is most consistent with being impact melt deposits based its occurrence as a relatively thin "cap unit" that overlies and/or embays P-type bedrock, and which manifest as coatings, veneers or flows that often varies in clast content within one contiguous unit. Polygonal textures are common in some locations and may be cooling contraction patterns or an erosional expression of the unit [7, 14-15]. This unit often forms small discrete erosional "windows" down into the underling P-type bedrock. In some cases, the unit can be observed to pond in low topographic areas on the uplifts and exhibits a variety of "swirl" and flow textures. Recently, spectral evidence for silicate glasses, interpreted to be impact glass [24] was discovered on CUs, and their spectrally mapped locations are consistent with previously mapped locations based on the HiRISE-scale morphologies described above. In some rare cases, this dark-toned unit also grades into occurrences of CRPM, which is consistent with the CRPM representing topmost portions of the crater-fill deposits [23-24]. Furthermore, CRPM are only observed in cases of the best-preserved and least eroded CUs. In the case of the dark-toned unit, clast content also increases with proximity to exposures of the underlying P-type bedrock or along contiguous flow features traversing from higher to lower elevations [see 8, 19]. On the other hand, CRPM appears to be relatively clast-poor at their surface, but have been observed to become increasingly clast-rich as the underlying bedrock surface is exhumed.

We also interpret a variety of cross-cutting tabular bodies ranging from several meters to as much as a km across as A-type dykes, some of which may be consistent with fault breccias as they appear to bound well-exposed megablocks in some CUs [see 17].

P-type Units. Detailed examinations of HiRISE images covering CUs, reveal three major P-type bedrock textures. These include: a generally light-toned fractured and massive bedrock (FMB), megabrecciated bedrock (MBB) and layered bedrock (LB – previously referred to as intact-layered stratigraphy [IS]) [see 4-6]. FMB appears to be a massive textured bedrock, possibly consistent with impacts likely into crystalline targets (i.e., plutonic bodies uplifted from depth) [5, 12]. MBB, which consists of clasts of various sizes, shapes and colours, appears to be best explained as resampled deposits from other impact events or possibly a discontinuous global megaregolith [5]. LB has been the most studied type to date, and is considerable interest for structural studies as the layers provide a frame of reference from which styles and the magnitude of deformation cab be recognized (e.g., faulting and folding) [5, 9-10, 16-17]. The majority of LB occurrences, particularly in the Tharsis region where it is most densely concentrated (~70% of all LB-dominated CUs), consists of what appear to be cyclic bedding of alternating relatively thin dark-toned and relatively thick light-toned layers that are on the order of ~3-40 meters in average thick [9]. These layers are not sedimentary, but are most consistent with interbedded lava flows and volcanic ash deposits based on the regional geology (predominately within the Hr unit) and some spectroscopic constraints. [4-5, 9, 11].

Structures. Different types of deformation features are observed to occur within Martian CUs. LB-type CUs are the most informative as the layers provide a frame of reference that enables the easy identification of structures such as faults and folds [4, 9-10, 16-17]. Breccia dykes are common and appear to be most prevalent in FMB CUs where incipient brecciation of the CUs megablocks are also most apparent.

Fractures, joints, faults, dykes and/or sills have been mapped in detail at a few localities. The fractures and joints observed in Ritchey Crater [14-15], a predominately FMB type CU, exhibits a strong radial pattern consistent with the formation of this structures during uplift, whereas structural mapping in LB craters [17] shows deviations from a radial pattern, which is likely due to dislocations parallel to layer-boundaries.

Ongoing and Future Work: Additional mapping of morphologic, structural and spectral features will continue to provide insights into impact target properties (e.g., influences from target volatiles, pre-existing structures, etc.), the impact process (e.g., impactite emplacement), and particularly the formation of CUs.

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