THE MARTIAN GEOMORPHOLOGY AS MAPPED BY THE MARTS EXPRESS HIGH RESOLUTION STEREO CAMERA (HRSC): IMPLICATIONS FOR GEOLOGICAL PROCESSES AND CLIMATE CONDIIONS.

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Introduction: One major reason for exploring Mars is the similarity of surface features to those present on Earth. Among the most important are morphological and mineralogical indicators suggesting that liquid water has existed on Mars at various locations over the entire history of the planet, albeit in decreasing abundance with time. The High Resolution Stereo Camera of ESA's Mars Express Mission (HRSC) is designed to simultaneously map the morphology, topography, structure and geologic context of the surface as well as atmospheric phenomena [1]. After 10 years of orbiting the planet, HRSC has covered about 90% of the surface in stereo and color with resolutions up to 10 m/pixel. High precision digital elevation models of up to 30-50 m grid spacing [1], generated from all suitable datasets of stereo coverage, currently cover about 40% of the surface [1,2]. The geomorphological analysis of surface features observed by the HRSC indicate major surface modification by endogenic and exogenic processes at all scales. Besides constraining the ages of surface features, HRSC also provides basic data for quantitative analyses to constrain the emplacement of volcanic material, fluvial erosional processes, glacial and periglacial surface modification, and eolian surface/atmosphere interactions.

Geomorphological changes with time: Endogenic landforms (e.g., tectonic rifts, small basaltic shield volcanoes) were found to be very similar to their equivalents on Earth [1,3-7], suggesting that processes unique to Mars may not be required to explain their formation. Volcanism may have been active up to the very recent past or even to the present, putting important constraints on thermal evolution models [4,6,7]. Mars' climate history is still subject to debate. Various erosional processes characterize Noachian landscapes. Landforms such as widespread valley networks, fluvial deposits and associated assemblages of hydrated clay minerals has led researchers to propose the hypothesis that the martian climate was at least considerably wetter during the early history of Mars [e.g., 8,9].

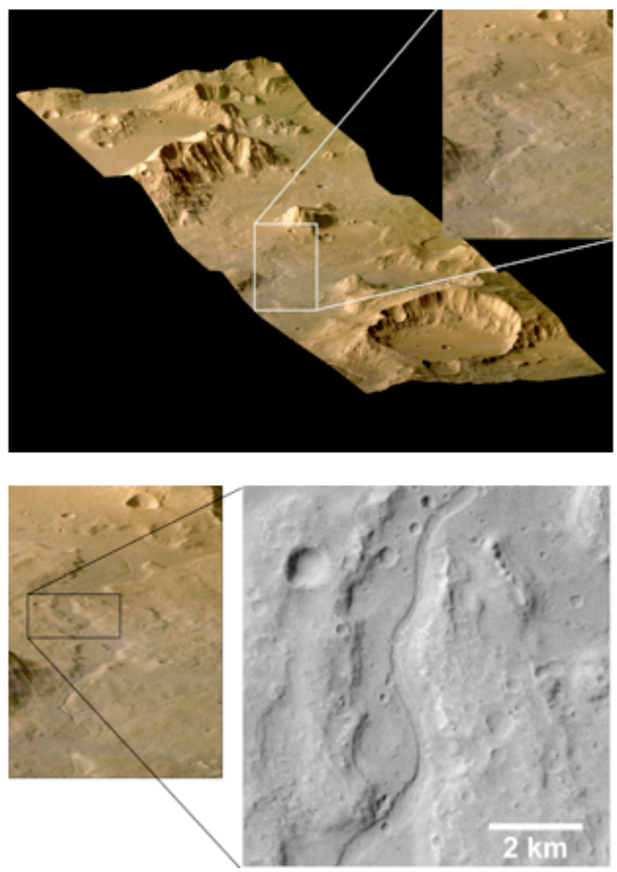

Fig. 1: Mars Express HRSC image of a valley system in Libya Montes. The valley exhibits an inner channel that shows erosional features of different ages [4,10].

At the boundary between the Late Noachian and Early Hesperian, environmental and climate conditions changed significantly and resulted in a transition towards a colder and drier climate. The intensity of aqueous activity decreased throughout the Hesperian, including a transition from long-term and repeated precipitation-induced fluvial activity towards reduced, short-term, spatially isolated and groundwater-dominated fluvial erosion [e.g., 10-13]. Figure 1 presents an exemplary valley network in Libya Montes, which has experienced different types of water release mechanisms and various periods of activity and quiescence [10]. By the end of the Hesperian, fluvial erosion had mostly ceased and volcanic, eolian and glacial processes are interpreted to be dominant on Mars. The Early Amazonian was already most likely characterized by a cold and dry climate that was similar to the conditions on recent Mars. However, Mars' climate and aqueous history, in particular the timing of the termination of dendritic valley network formation due to widespread surface runoff and the transition from precipitation-induced toward groundwater-dominated erosion such as sapping and outflow channel formation, is still subject to debate. The analyses of diverse landforms produced by aqueous processes revealed that surface water activity was likely episodic, but ranged in age from very ancient to very recent [1,14-22]. Particularly important are prominent glacial and periglacial processes at several latitudes, including mountain glaciers and a frozen sea [23-31]. The identification of aqueous alteration minerals and their geological context has enabled a better understanding of paleoenvironmental conditions and pedogenetic processes [32-33]. Dark dunes contain volcanic material and are evidence for a very dynamic surface, characterized by widespread erosion, transport, and redeposition [34]. Recently formed gullies and alluvial fans might have experienced even shorter periods of liquid water (minutes to hours), as shown by the identification of debris flow deposits that were formed by short-lived high-energy mass-wasting events [19]. However, most gullies show morphological characteristics, which indicate that they were formed by repeated flow events involving fluvial-dominated processes, such as snow deposits melting during high-obliquity phases [31, 35].

Comparable environmental conditions: The surface of Mars shows many landforms that resemble cold-climate features on Earth. Permafrost on Earth is known to host rich habitats containing cold- adapted microbial communities. Permafrost environments on Mars might represent habitable zones if liquid water is present, e.g., as a consequence of freeze-thaw cycles. Since basically all geologic interpretations of extraterrestrial features require profound knowledge of the Earth as key reference, thus, studying terrestrial analogues is mandatory in planetary geology. Field work in Antarctica, Svalbard and Iceland [27,30,36,37] using similar instrumentation as on Mars provided a basis for the analyses of periglacial and volcanic processes, respectively.

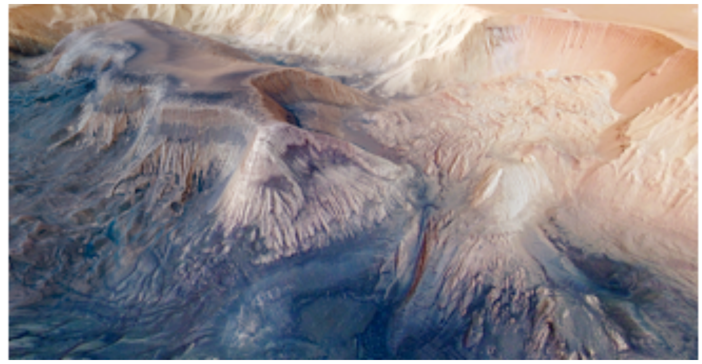

Fig.2: Depositional and erosional features in Hebes Chasma, HRSC stereo false color composite.

References*:* [1] Jaumann et al., 2007, PSS 55; [2] Gwinner et al., 2010, EPSL 294; [3] Neukum et al., 2004, Nature 432; [4] Neukum et al., EPSL 294; [5] Hauber et al., 2005, Nature 434; [6] Hauber et al., 2009 PSS 57; [7] Platz and Michael, 2011, EPSL 312; [8] Sagan et al., Science, 181, 1045-1049, 1973; [9] Andrews-Hanna and Lewis, JGR, 116, E02007; [10] Jaumann et al., EPSL, 294, 272-290, 2010; [11] Harrison, and Grimm, R.E., JGR, 110, 2005; [12] Erkeling, G., et al., EPSL, 294, 291-305, 2010; [13] Carr, Philosphical Transactions of the Royal Society A, 370, 2193-2215, 2012; [14] Jaumann et al., 2005, GRL 32; [15] Jaumann et al., 2010, EPSL 294; [16] Erkeling et al., 2012, Icarus 219; [17] Raack et al., 2012, Icarus, 219; [18] Kleinhans et al., 2010, EPSL 294; [19] Reiss et al., 2009, PSS 57; [20] Kneissl et al., 2010, EPSL 294; [21] Di Achille et al., 2006, JGR 111; [22] Di Achille et al., 2006, GRL 33; [23] Head et al., 2005 Nature 434; [24] Murray et al., 2005 Nature 434; [25] Pacifici et al., 2009, Icarus 202; [26] Rossi et al., 2011, Geol. Soc. Am.356; [27] van Gasselt et al., 2011, Geol. Soc. Am. 356; [28] Shean et al., 2005, JGR 110; [29] Marchant et al., 2006 EPSL 241 663-671; [30] Marchant and Head, 2007, Icarus; [31] Head et al., 2010 EPSL, 294, 306-320; [32] Le Deit et al., 2010, Icarus 208; [33] Le Deit et al., 2012, JGR 117; [30] Bishop et al., 2013, JGR 118; [34] Tirsch et al., 2011, JGR 116; [35] Head et al., 2008 EPSL, 294, 306-320; Proceedings of the National Academy of Sciences 105, 13,258--13,263; [36] Ulrich et al., 2011 Geomorphology 134; [37] Hauber et al., 2011, Geol. Soc. Am. 483.