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Quantifying geological processes on Mars—Results of the high resolution stereo camera (HRSC) on Mars express ☆

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ABSTRACT

This review summarizes the use of High Resolution Stereo Camera (HRSC) data as an instrumental tool and its application in the analysis of geological processes and landforms on Mars during the last 10 years of operation. High-resolution digital elevations models on a local to regional scale are the unique strength of the HRSC instrument. The analysis of these data products enabled quantifying geological processes such as effusion rates of lava flows, tectonic deformation, discharge of water in channels, formation timescales of deltas, geometry of sedimentary deposits as well as estimating the age of geological units by crater size–frequency distribution measurements. Both the quantification of geological processes and the age determination allow constraining the evolution of Martian geologic activity in space and time. A second major contribution of HRSC is the discovery of episodicity in the intensity of geological processes on Mars. This has been revealed by comparative age dating of volcanic, fluvial, glacial, and lacustrine deposits.

Volcanic processes on Mars have been active over more than 4 Gyr, with peak phases in all three geologic epochs, generally ceasing towards the Amazonian. Fluvial and lacustrine activity phases spread a time span from Noachian until Amazonian times, but detailed studies show that they have been interrupted by multiple and long

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lasting phases of quiescence. Also glacial activity shows discrete phases of enhanced intensity that may correlate with periods of increased spin-axis obliquity. The episodicity of geological processes like volcanism, erosion, and glaciation on Mars reflects close correlation between surface processes and endogenic activity as well as orbit variations and changing climate condition.

1. Introduction

Imagery is one of the major sources for our current understanding of the geologic and climatic evolution of Mars in qualitative and quantitative terms. The High Resolution Stereo Camera (HRSC) of ESA's Mars Express Mission is designed to simultaneously map the topography, morphology, structure and geologic context of the surface as well as atmospheric phenomena (Neukum et al., 2004b; Jaumann et al., 2007). After 10 years of orbiting the planet, HRSC has covered more than 90% of the surface with image resolutions up to 10 m/pixel. High precision digital elevation models of up to 50 m grid spacing (Gwinner et al., 2009, 2010), generated from all suitable datasets of stereo coverage, currently cover about 40% of the surface (Fig. 1).

The HRSC directly addresses two of the main scientific goals of the Mars Express mission: (1) High-resolution three-dimensional photogeologic surface exploration and (2) the investigation of surface–atmosphere interactions over time; and significantly supports (3) the study of atmospheric phenomena by multi-angle coverage and limb sounding as well as (4) mineralogical mapping by providing high-resolution three-dimensional color context information. In addition, the stereoscopic imagery is especially used for characterizing landing sites and their geologic context (Jaumann et al., 2007; Gwinner et al., 2015). HRSC data provide the basis for extensive studies of the surface structure and morphology on local, regional and global scales using textural information from the panchromatic channel, the topographic information from the digital terrain model as well as from orthorectified images, and spectral information from color channels. Information on physical surface properties by means of multi-phase angle observations supports the geologic context characterization. The major result of these studies is the identification of geologic units in terms of structure, age and compositional heterogeneities. The relationship of different geologic units will build up stratigraphic sequences, which are used to model the processes that formed the specific surface. The stereo images are also used to refine the geodetic reference system of Mars and to improve the Martian cartographic database by providing digital topography data from global mapping at high spatial resolution (see Gwinner et al. (2015) for related methodology and results). Variable surface features and atmospheric phenomena are mapped at high resolution and are used for temporal interpretations of atmosphere/surface interacting processes. Finally, high-resolution observations of Phobos and Deimos help to refine the ephemerides of the moons and are used to understand their geologic and orbital evolution (Wählisch et al., 2014; Willner et al., 2014). A comprehensive evaluation of dedicated sets of Mars Express instrument data including HRSC will improve the overall mission output by combined structural/compositional investigations using HRSC and the spectrometer OMEGA as well as by combined surface/sub-surface investigations using HRSC and the radar instrument MARSIS. This is also valid for combining HRSC data with other mission data such as Viking, MOC, MOLA, THEMIS, CRISM, HIRISE and data from upcoming missions.

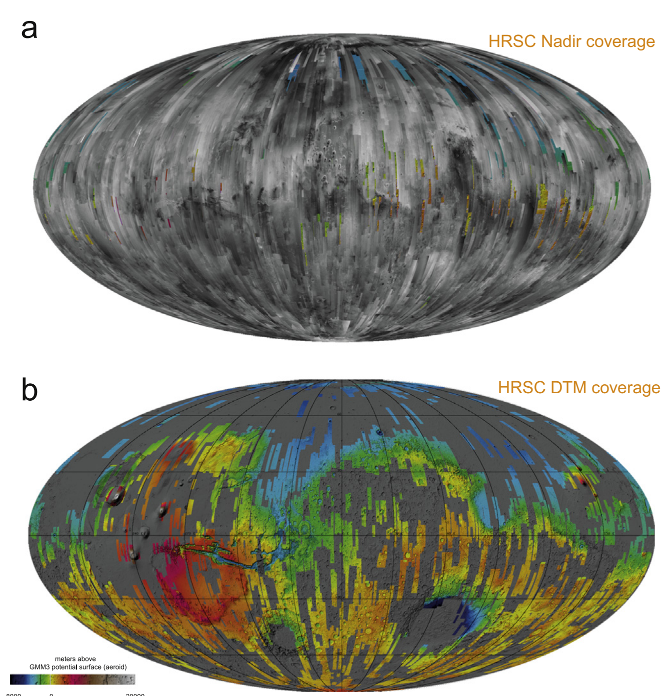

Fig. 1. HRSC coverage maps. (a) Total image surface coverage of HRSC as of orbit 13,021. Global HRSC nadir mosaic (gray) draped onto color-coded MOLA topography. (b) Coverage of high-level digital terrain models derived up to orbits 6509. Color-coded shaded relief maps from HRSC single-strip DTMs overlaid onto MOLA shaded relief map in gray (see Gwinner et al. (2015) for further detail). All data are available via PSA and PDS.

The unique multi-angle imaging technique of the HRSC supports its stereo capability by providing not only a stereo triplet but also a stereo quintuplet (Jaumann et al., 2007). The HRSC surface resolution and the digital terrain models provide the context between highest ground resolution images and global coverage observations and are also used as cartographic basis to correlate between panchromatic and multispectral data (Fig. 2). As the mission is still ongoing, existing coverage gaps can be gradually closed over the next years Fig. 3.

Among the terrestrial planets, Mars is intermediate in size between the small bodies Moon and Mercury and the larger Venus and Earth. As such, Mars shares common characteristics with both groups, such as the retainment of very old surfaces that is typical for bodies with small mass and rapid cooling. On the other hand, Mars displays evidence for endogenic activity that spans basically all of its history, which would be expected for planets with larger mass. This diversity and longevity of endogenic processes is accompanied with a diversity of exogenic processes. Among the most important findings with respect to exploration are morphological and mineralogical indicators suggesting that liquid water may have existed on Mars at various locations over almost the entire history of the planet, albeit in decreasing abundance with time (e.g., Mangold et al., 2007, 2008c; Ansan et al., 2008; Carr and Head, 2010; Ansan et al., 2011; Loizeau et al., 2012). Geomorphological analyses of surface features observed by the HRSC indicate major surface modification by endogenic and exogenic processes at all scales (e.g., Jaumann et al., 2014a). Besides constraining the