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Mars Exploration Accomplishments: Orbital Perspective in context with Mars Express

R. Jaumann[1,2] S. Adeli[1], D. Tirsch[1], K. Gwinner[1]

[1]German Aerospace Center (DLR), Inst. of Planetary Research, Berlin, Germany, [2]Freie Universitaet Berlin, Inst. of Geological Geosciences, Berlin, Germany. Ralf.Jaumann@dlr.de

Introduction: Numerous spacecraft observed or still observe the Martian surface, subsurface, atmosphere and environment including Mars Global Surveyor, Mars Odyssey, Mars Express, Mars Reconnaissance Orbiter, Mars Orbiter Mission, Maven, and ExoMars Trace Gas Orbiter. Cameras, spectrometers, laser altimeters, and radar experiments enabled investigations of geological processes, interactions of the interior with the surface as well as of the surface with the atmosphere and the exosphere. The spatial resolution of image data reaches ~10 cm/pixel in places [1,2], the global coverage reaches even up to ~98% with a resolution better than 20 m/pixel in color [3,4]. Topographic data reach ~10 m/pixel with stereo imaging [3,4] and laser altimetry [5]. Spectral observations in the visible and infrared spectral range yield compositional information about the surface and atmosphere [e.g.,6,7,8,9] as well as information on thermal surface properties [10,11] and shallow subsurface hydrogen content by gamma ray measurements [12]. Radar experiments provided insight into the subsurface [13,14] down to ~4 km depth.

Accomplishments: Geomorphological analyses of the Martian surface indicate major modifications by endogenic and exogenic processes on all scales. Endogenic landforms (e.g., tectonic rifts and basaltic shield volcanoes) were found to be very similar to their equivalents on Earth, suggesting that no unique processes are 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 [e.g.,15,16,17,18]. Dark dunes contain volcanic material and are evidence for a dynamic surface environment, characterized by widespread erosion, transport, and re-deposition [e.g., 19,20,21]. The analysis of diverse landforms produced by aqueous processes revealed that surface water activity was likely episodic. The amount of liquid water, however, reduced from ancient large paleolakes and valley networks to local outflow channels existed in the recent past (late-mid Amazonian) [e.g.,15,16,22,23]. Particularly important are prominent glacial and periglacial features at polar regions and mid-latitudes, including debris-covered glaciers [e.g.24,25,26]. The identification of hydrated minerals and their geological context has enabled a better understanding of paleoenvironmental conditions and pedogenetic processes [e.g.,26,27]. External processes, affected the evolution and vigor of the Martian hydrologic cycle and influenced the distribution and state of water on, and within, the planet's crust [e.g.,18] with progressively shrinking reservoirs of groundwater [28]. Various phyllosilicates formed by pH-neutral aqueous alteration very early in the planet's history are found in the oldest, Noachian-aged terrains; sulfates, on the other hand, are indicative of an acidic environment and were formed later during Hesperian times [26,29]. Beginning about 3.0 billion years ago, the Amazonian epoch is dominated by the formation of anhydrous ferric oxides in a slow superficial weathering, with limited and short-lasting surface liquid water across the planet [26]. While the planet's first billion years, with differentiation, hydrodynamic escape, volcanism, large impacts, erosion, and sedimentation rapidly modified the atmosphere and crust [e.g.,18] geological processes in the following epochs ceased but still had the power to change the surface. In addition, remote sensing of Mars has revealed that the surface is continually changing [e.g., 30-32] by modifications due to exogenic processes, including aeolian activity, mass movements, the growth and retreat of the polar caps, and crater-forming impacts. Although it could be confirmed from orbit that numerous geological processes were active on Mars and that water played a major role all over its history, small-scale geochemical and possible biochemical processes are not accessible by remote-sensing from orbit but need in-situ and sample analyses accomplished by rovers and landers. Such landing missions need to count on reliable and precise terrain information provided by orbiter missions for enabling a safe landing on Mars. High-resolution digital elevation models from HRSC on-board Mars Express are a precious tool used for selecting landing sites of past and upcoming Mars *in situ* missions (e.g., MSL, ExoMars EDL, Insight (Fig. 1), ExoMars Rover (Fig. 2), and Mars 2020 (Fig. 3).

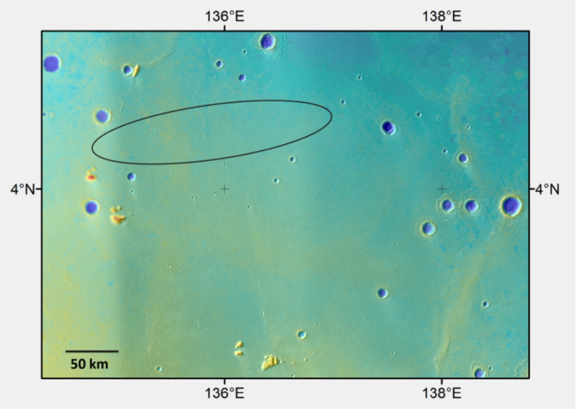

Fig. 1: HRSC DTM of the InSight mission landing site (black ellipse; landed in November 2018 on Mars) located in the flat plains of Elysium Planitia. DTM spatial resolution is 50 m per pixel; north is to the upper right).

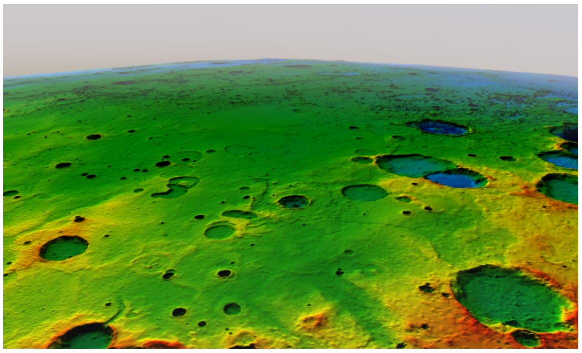

Fig. 2: HRSC perspective view of the Oxia Planum region comprising the selected landing site (flat area in the center of the image) for the upcoming ExoMars rover, which shall be launched in 2020. DTM spatial resolution is 50 m per pixel; image width is about 180 km; north is to the upper right).

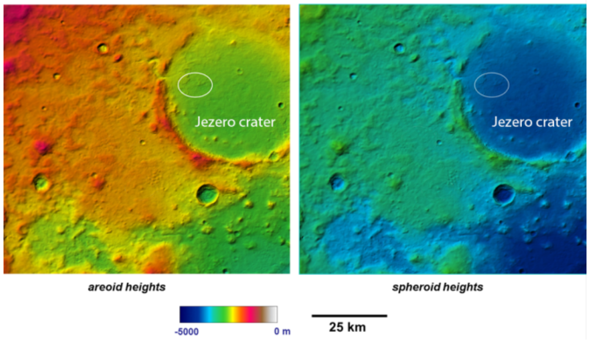

Fig. 3: HRSC DTM mosaic of the Mars 2020 rover landing site within Jezero crater. View shows comparison between height above areoid and spheroid, respectively.

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