NEW INSIGHTS INTO THE GEOLOGICAL EVOLUTION OF MARS THROUGH THE MARS EXPRESS HIGH RESOLUTION STEREO CAMERA (HRSC)

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Introduction: After two years of orbital acquisition of high-res stereo and color data by the HRSC experiment [I] on the ESA Mars Express Mission and nearly 30% coverage of the martian surface at a resolution of better than 20m/pixel, we are beginning to understand the geological evolution of Mars at different scales (globally, regionally, and locally) considerably better. The combination of the new HRSC data with MOC data where high-res context information can be merged with detailed local information, and the combination with color data giving the distribution of different materials as well as stereo viewing capability open up a new domain of photogeological high-precision interpretation.

Main Results: Now a first synthesis of our investigations can be attempted in the areas of volcanism and fluvial and glacial activity through the history of Mars, and the sequence of events can be determined much beyond what has been published in [2] already by the HRSC Team. There it had become clear that Mars has been active in terms of volcanic, hydrothermal, fluvial, and glacial activity until recently. Now, we can demonstrate that there has been episodic activity throughout the whole history of Mars though declining in magnitude through time and peaking at certain periods in the past, becoming confined more and more to certain regions or locales, such as the poles, the highland-lowland boundary and in particular the Tharsis and Elysium regions and vicinities. A concentration of volcanism in more recent times on Tharsis and Elysium was clear already during Viking and early post-Viking times (cf [3]), and the cronostratigraphic relationships had been investigated especially by [4]. The early results are largely compatible with our new findings compiled in [5] and presented here for some major findings. Especially the early cessation (~ 3.5 Ga ago) of martian highland volcanism and the concentration of volcanism in Tharsis and Elysium is confirmed by a wealth of new data. What is becoming much clearer now is that in parallel to the cessation of the martian highland volcanism ~3.5 Ga ago and probably the rapid loss of the martian atmosphere within a few 100 Ma by that time, Mars fell dry on a global scale. At that time, as is hypothesized here, probably most of the previous atmospheric moisture that existed in the once denser martian atmosphere was dumped on the surface in form of a dusty ice-rich layer of several hundred meters of thickness. Such a layer has been identified even in near-equatorial areas on Olympus Mons [2, 6] where it survived in residues until today. This layer might be the same as the global mantling deposit identified on the basis of Viking imagery by [7]. From this layer, subsequently often covered by new lava flows, water was probably released throughout martian history by heating from underground "geothermally". The volcanic activity of Mars through time seems to have been directly related to such activities, and we see a close interaction and parallelism in time between volcanism and fluvial as well as glacial activity as demonstrated by [2] and [6], and as we see in our new findings described here. In Fig. 1, we have compiled the major episodes we found for martian volcanic, fluvial, and glacial activity from early times until today. There appears to be a remarkable coincidence between the age groups found for martian meteorites [8, 9] and our results as already pointed out by [2] and [5] on the basis of a more limited HRSC data set.

Evolution of Kasei Valles and Related Fluvial/Glacial Activity: In order to better understand the fluvial/glacial history of Mars that was most prominently coupled to the formation and evolution of outflow channels, we have investigated Kasei Valles and its source region Echus Chasma, where we also have identified a dusty ice-rich layer on the Echus Chasma plateau. The area investigated is shown in Fig. 2. From the Echus Chasma Plateau, Kasei Valles was fed with water 3.5 Ga, ~1.5 Ga, and ~600 Ma ago. These ages show up as main episodes of activity in our cratering age data, examples of which are shown in Fig. 2. It appears that volcanism has played a major role in melting the dusty ice-sheet, delivering water to the outflow channel through wide shallow channels and a dendritic network on the plateau which was already identified by Mangold et al. [10]. In that paper it was claimed that this happened in Hesperian time. Now on the basis of our data it is clear that the chronostratigraphic relationships were not fully understood by [10] but that the release of water continued in a major way to more recent times with a peak coinciding with the volcanic activity around 1.4 – 1.7 Ga ago. After 1.3 Ga ago the supply of water appears to have dropped drastically and the glacier that had developed downstream in Echus Chasma and had been active from at least 2.6 Ga until 1.3 Ga ago vanished. Later activity in Echus Chasma (400-700 Ma ago) does not seem to have re-established the glacial activity in any major way downstream but ice-rich layers were formed in places in the main channel of Kasei Vallis. Our new data show that the activities in Kasei Vallis at least from 2.6 Ga onwards have been glacial rather than fluvial as already suspected by Lucchitta [11]. Uranius Dorsum, the "enigmatic ridge" as termed during Viking times formed by a lava flow from the north-west 2.6 Ga ago, and which was stopped and piled up by the then existing ice sheet.

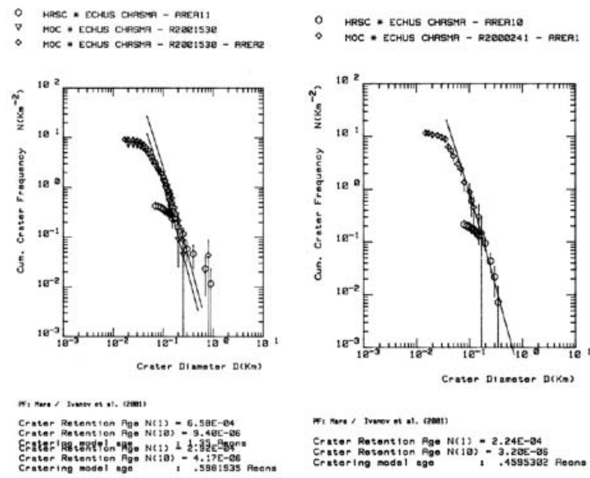
Conclusion: It is now very clear on the basis of our analysis of HRSC data and as has been pointed out by Bibring et al. [16] on the basis of OMEGA spectral data, the early "wet and clement" Mars as put forward after Viking, is more of a fiction than reality. Whether a global large ocean in the north ever existed is less clear than ever, the odds seem to be against it. At least by 3.5 Ga ago, probably already around 3.8 Ga ago, our data tell us, it was gone if it was there before and Mars fell dry rapidly on a global scale. Nevertheless, from time to time through the Aeons until today Mars has been volcanically active in periods, and largely through this activity water seems to have been released from ice-rich layers on the surface or sub-surface or from aquifers which formed fresh small-channel systems locally and triggered glacial processes through the freezing water.

Validity of Ages: The age data presented here have been obtained by applying the Hartmann & Neukum chronology [12]. Our method making use of small craters was criticized by McEwen et al. [13]. As pointed out already by Hartmann [14], McEwen et al.'s critique is not well based but essentially erroneous and contradictory in itself. McEwen et al.'s arguments which are mainly theoretical have recently been throroughly analyzed by Werner [5] and Werner et al. [15] on the basis of mainly hard empirical data. We have been able to demonstrate in these papers on top of Hartmann's arguments that McEwen et al.'s reasoning is totally invalid.

References: [1] Neukum, G. et al., *ESA SP-1240*, 2004; [2] Neukum, G. et al., *Nature 432*, 2004; [3] Wilson, L. et al., J., *Geophys. Res. 106*, 2001; [4] Neukum, G. & Hiller, K. J., *Geophys. Res. 86*, 1981; [5] Werner, S., *Doctoral Dissertation*, 2005; [6] Basilevsky, A. T. et al., *Solar System Research* 39, 2005; [7] Mustard, J. F. et al., *Nature 412*, 2001; [8] Nyquist, L. E. et al., *Space Science Rev. 96*, 2001; [9] Borg, L. & Drake, M. J., *Geophys. Res. 110*, 2005; [10] Mangold, N. et al., *Science 305*, 2004; [11] Lucchitta, B. K. et al., *Nature 290*, 1981; [12] Hartmann, W. K. & Neukum, G., *Space Sci. Rev. 96*, 2001; [13] McEwen, A. S. et al., *Icarus 176*, 2005; [14] Hartmann, W. K., *Icarus 174*, 2005; [15] Werner, S., *this conference*, 2006.; [16] Bibring, J. et al, Nature, 428, 2004.

AGE	PROCESSES	STRUCTURES
<10 Myr	Youngest volcanic and glacial structures, episodic occurrence of liquid water	Hellas Montes, Elysium area Highland-Lowland Dichotomy Olympus and Tharsis Montes
<90 Myr and younger	Volcanic flows, partly coupled with melting of ground ice	Kasei Valles, Echus Chasma, Olympus Mons East
150-200 Myr	Volcanic flows at the large shield volcanoes trigge-ring fluvial and/or glacial activity	Olympus and Tharsis Montes Kasei Valles
400-700 Myr	Fluvial activity, probably triggered by volcanism	Mangala Valles Ares and Tiu Valles
1.4-1.7 Gyr	Fluvial activity, probably triggered by volcanism	Echus Chasma/Kasei Valles Medusae Fossae Formation
~3.5 Gyr	Highland volcanism ceased Outflow channel formati-on (major period) ended. Ocean – if existing – dried up	Hadriaca Patera Kasei, Ares and Tiu Valles and Iani Chaos

Fig. 1: Episodic, volcanic, fluvial, glacial activity throughout Martian history.



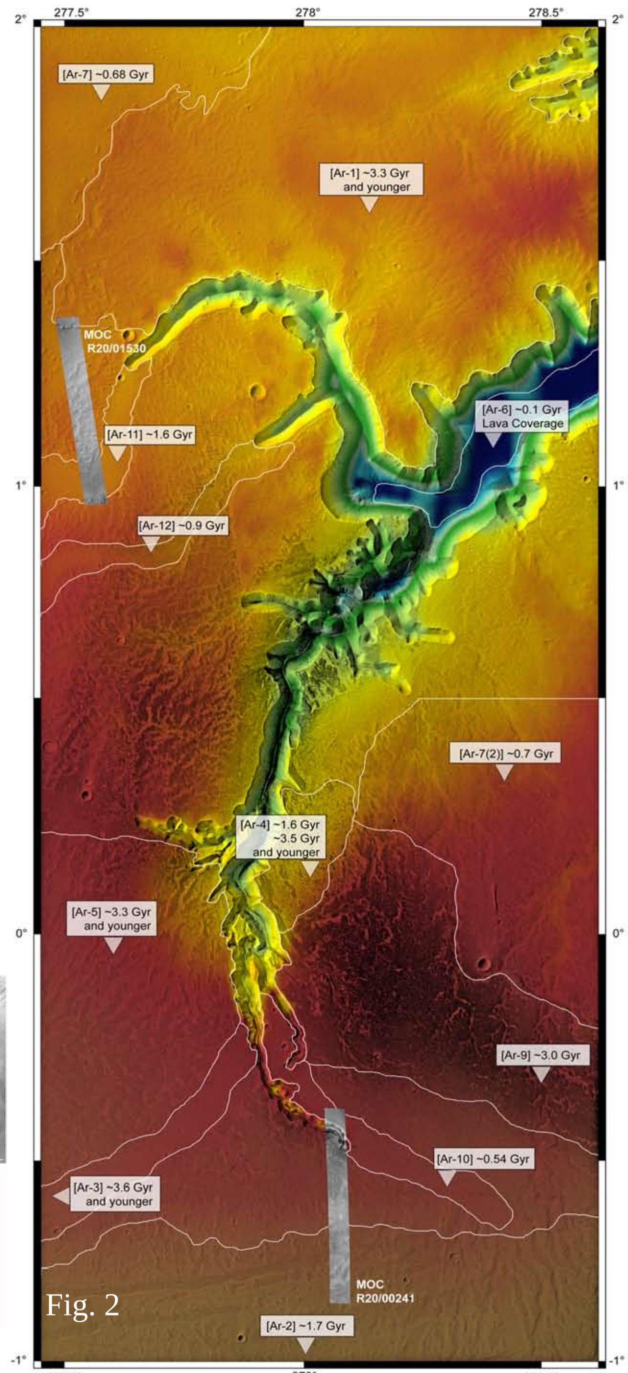


Fig. 2

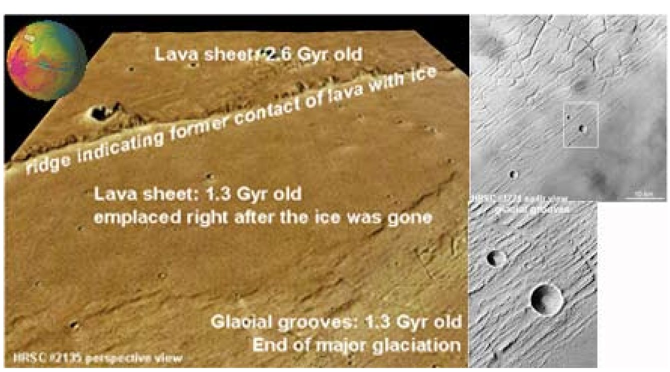


Fig. 3