

ESTIMATES OF THE EROSION RATES ON MARS OVER TIME AND THEIR IMPLICATIONS FOR THE EVOLUTION OF THE ATMOSPHERE. C. Quantin¹, R. A. Craddock², F. Dubuffet¹, L. Lozac'h¹, M. Martineau¹, ¹ Laboratoire de Géologie de Lyon Terre, Planètes, Environnement (CNRS-ENS Lyon-Université Lyon1), ERC eMars Team, 2 rue Raphaël Dubois 69622 Villeurbanne Cedex, France, ² Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, District of Columbia, USA

Introduction: Despite many studies and observations about the processes that occurred on early Mars, we have yet to reconstruct a reliable temporal model that relates the geology to the past climate. Geologic features such as modified impact craters [i.e.1,2], valley networks [3], and outflow channels [4] attest to the fact that liquid water was once stable on the Martian surface and erosional processes occurred. In order to support the geologic evidence of surface erosion, the Martian atmosphere must have been significantly thicker than today. If so, how long did such an atmosphere persist? Was it periodic, episodic or sustained? Was the climate change related to atmospheric escape or cessation of the magnetic dynamo? Here we conduct an analysis of eroded features on Mars in an attempt to determine how the rate of erosion may have changed over time.

Crater size distributions of a planetary surfaces, and especially older surfaces of Mars, record both the cratering rate and the geological history. Variations from a theoretical crater size distribution that would result from meteoritic bombardment is interpreted as erosional or depositional processes and is called the Opick Effect [5,6]. From early as the Mariner missions, such processes have been suggested to explain the difference between Martian crater size distributions and similar one from the Moon [7, 8, 9]. Moreover, the fact that craters are preserved at different stages of modification at different diameters indicates that the modification process must have been erosional and long-lived, continuing to erode craters as they formed [10, 2]. Craters are ubiquitous features that have formed continually over time, so by analyzing their size frequency distributions, it is possible to infer temporal changes in geologic processes and by inference the evolution of the early Martian atmosphere and climate.

To accomplish this, we developed a simple numerical model that reproduces impact cratering while the surfaces is undergoing erosion or deposition, which would affect the preserved crater populations. This model generates synthetic crater size distributions that we further used to interpret ~70 crater populations located in different regions of the Martian surface. The resulting analysis allows us to decipher the erosion (or deposition) rate from the geological record and—for

the first time—quantitatively assess how it may have changed over time.

Method: We designed an iterative model that simulated crater populations as they would appear after being subjected to obliteration from erosion and burial over 1 My time intervals. The model is one-dimensional as individual impact craters are stored in the model output as a single depth. We used the crater size distribution from [11] and converted this to a crater depth distribution following the empirical law of crater depth and diameter from MOLA measurements of fresh impact craters [12]. Then using the impact rate model from [13], we estimate the impact cratering that accumulate every 1 My at any period of the history of Mars. Simultaneously, we applied various obliteration rates. Both the obliteration rate and the impact rate can change over time. After several iterations, craters begin to disappear from erosion or burial while new craters form. As a convention, a crater is removed from the model crater population when its depth is less than 1 meter. We ran the model to include the effects of several Gy of changes at increments of 1 My. At the end of the simulations, the model produces a synthetic crater size distribution that integrates both the impact cratering rate history and obliteration rate history, which we then compared to actual crater populations to estimate the effective erosion rate that the craters had been subjected to.

The free parameter of the model is the obliteration rate history. As we have no idea about how the erosion rate may have changed over time, we started with two simple biphasic erosion rate models. The first one corresponds to two successive periods during which the obliteration rate was held constant [Figure 1A] and the second modeled an erosion rate that decreased linearly over time [Figure 1 B].

Crater data used for input. We used the global crater data base from [14] that is reported to be inconclusive of crater 1 km in diameter and larger. To place these data into temporal and geologic context, we defined a hundred large areas on Mars that were located primarily in Noachian terrains, but several in Hesperian and Amazonian terrains as well. Basically, our goal was to assess crater erosion rates through all of geologic time were it was possible. The areas had to be large

enough to have a sufficient number of craters larger than 60 km while located in a coherent geological unit (from 10^5 to 10^6 km²). We used a cylindrical equal area projection to compute the area of each zone. Using GIS techniques, crater size distributions of each area are extracted and used for the analysis.

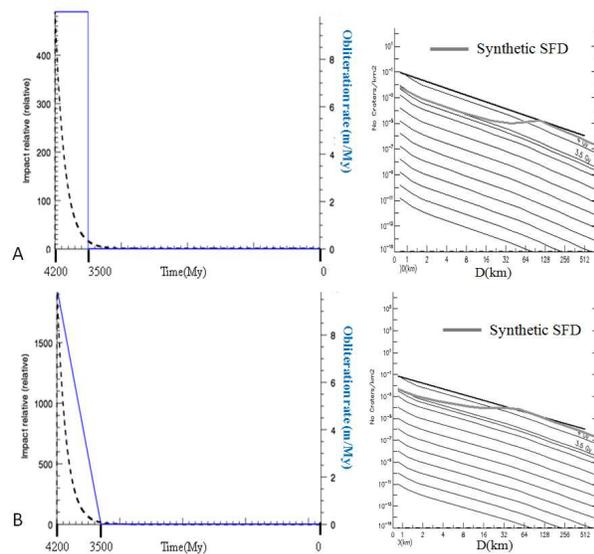


Figure 1: Cratering and erosion evolution model (left) applied to generate the synthetic crater size distributions (right) plotted here in incremental representation that is more sensitive to the Opick Effect [2]. Figure 1A illustrates the biphasic model with 2 periods of constant obliteration rate. B) Figure 1B illustrates the biphasic model with an old period experiencing a decreasing obliteration rate with time.

Erosion Rate Estimates: We fixed the current obliteration rate on Mars to 0.01m/My, which corresponds to the value deduced from rover measurements [15]. The maximum erosion rate in both endmember erosion rate models is the only parameter to be returned when analyzing the individual crater populations. To do this, we used optimization techniques that sought the solution that best fits the data within an error of 0.1 m/My. The initial age as well as the age when the surface becomes stable is determined directly from the parts of the crater size distribution that follow the isochrones for several crater size bins.

For instance, we apply the model to best fits the crater size distribution of all noachian terrains. The average age of Noachian terrains is 3.9 Gy according to age model from [13] and the terrains would have experienced a period of intense crater obliteration of

4.1 m/my that ended at 3.45 Gy according the first bi-phasing model.

Results: We then applied this approach to inverse the extracted crater size distributions for all the selected areas of Mars to better understand the temporal evolution of crater obliteration rates. The results show that the ages of the analyzed surfaces ranging from 4.2 Gy to 2.8 Gy and that the age of the change in magnitude of the obliteration rate varies from 3.7 Gy to 700 My. Indeed, we observe a large diversity from an area to another, as it can be expect on a geologically diverse planet like Mars. But, this diversity is also highly important for retrieving the timing of crater obliteration and erosion rates. According to both models there was a steady decrease in the erosion rate on the order of 2-3 order of magnitude 4.2 Gy to 2.5 Gy Both models also indicate that there was a steady decrease in the crater obliteration rate with time. Spikes, rapid decreases, or sudden shifts in the obliteration rates are not observed.

Conclusions: Our results indicate that there was not some sort of special climatic conditions that were maintained during the Noachian or that a thicker primordial atmosphere suddenly disappeared. Rather, the early atmospheric conditions that were capable of supporting surface liquid water simply waned gradually over time.

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References: [1] Craddock and Howard, 2002, JGR-Planet ,07. [2] Mangold et al., 2012, JGR-Planet, Vol 117; [3] V. Ansan, N. Mangold, , JGR-Planet ,118 (2013). [4] V.R. Backer, 2001, Nature, 412. [5] Hartmann W.K., 1966, Icarus, Vol. 5, pp. 565-576; [6] Hartmann W.K. and Neukum G., 2001, Space Sci. Rev., Vol. 96, p.165-194; [7] Jones, 1974, JGR, Vol 79, p3917-3931; [8] Hartmann, 1971, Icarus, Vol15, p410; [9] Chapman, Icarus, 1974; [10] Craddock and Howard, 1997, JGR-Planet ,102, [11] Hartmann, 2005, Icarus 174, [12] Garvin and Frawley, 1998, GRL, 25, [13] Neukum, G. et al., 2001, Space Sci. Rev., Vol. 96, p.55-86. [14] Robbin and Hyneck, 2012, JGR, Vol 117; [15] Golombek et al., 2006, JGR-Planet , 111.