The Evolution Of The Martian Atmosphere Inferred From Analyses of Crater Obliteration Rates.

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Introduction

Despite recent observations about the processes that occurred on early Mars, we have yet to reconstruct the early climatic evolution of the Red Planet. Did Mars experience an early wet and warm climate as suggested by the presence of valley networks on Noachian terrains? If so, how long and intense (in term of erosion rates) was this wet period? Was this warm and wet period episodic or sustained? How this is related to atmospheric escape or the magnetic dynamo?

Crater size distributions of a planetary surfaces, and especially old 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 [1,2]. 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 [3, 4, 5]. Using numerical modeling and comparisons to crater size distribution observed in Mariner images an increase the rate of crater obliteration was proposed for the middle of Martian geologic history [3]. More recently, [6] propose a change in the crater erosion style around 3,7 Gy possibly linked with the end of the dynamo activity and its putative effect on the retention of a denser primordial atmosphere. The evolution of a primitive dense atmosphere is still an open question that recent observations of both the surface and atmosphere have yet to solve.

Here we use an approach similar to [3] but added with modern computation facilities and an exhaustive catalog of Martian craters [7]. We developed a numerical model to generate synthetic crater size distributions while applying a model of impact rate evolution as well as a model of obliteration rate evolution. We then used the model results to inverse about 70 crater size distributions extracted from large areas on Mars. First, we present the model and the inversion method. Then, we present the results that allow us to constrain the atmospheric evolution of early Mars.

Method

The model: To build the model of crater obliteration rate we used the cratering rate model defined by [8] from the cratering analysis of the lunar surface and Apollo sample radiometric ages and applied to Mars [2]. The temporal resolution of the model is 1 My. For each period of Mars history, the model calculates the number of impact craters per surface unit for each crater size bins defined by [2]. Based on the crater diameter to depth ratio, we estimate the average crater depth of a crater size bin. Simultaneously, we apply an obliteration rate. We used increments of 1 m of erosion depth to remove the crater from the record. The model produces a synthetic crater size distribution that integrates both the impact cratering rate history and obliteration rate history for comparison to the actual crater size frequency distribution curves. The free parameter of the model is the obliteration rate history. As we have no idea of the evolution of the obliteration rates, we start with two simple biphasic models. The first one corresponds to two successive periods during which the obliteration rate has been constant [figure 1 A] and the second constrain a linear decrease of the obliteration rate during the oldest period [Figure 1 B].

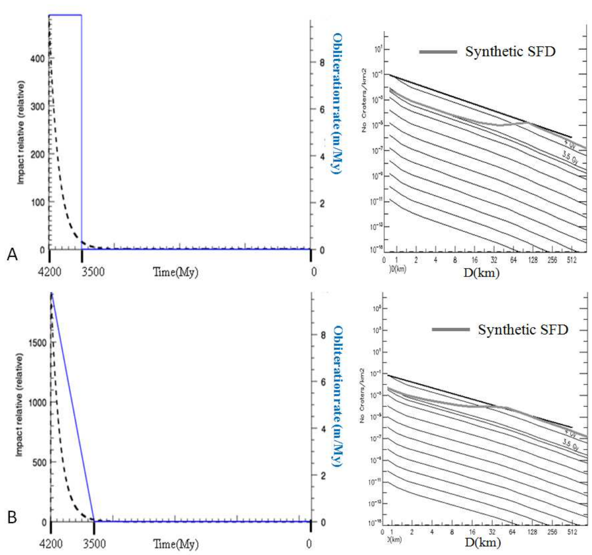

Figure 1: Cratering and erosion evolution model (left plots) applied to generate the synthetic crater size distributions (right plots) plotted here in incremental representation that is more sensitive to the Opick effect [2]. Figure 1A illustrates the biphasic model with 2 periods of constant obliteration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

Inversion: We used a variable approach for the inverse problem to determine the age of the terrain, the age of the change in erosion regime as well as the obliteration rate during the oldest period from crater size distribution. The starting age and as well as the age of the change of obliteration regime is directly inversed from the parts of the crater size distribution that follow the isochrones for several crater size bins. We arbitrarily fixed the obliteration rate of the recent period to the erosion rate estimated by the Martian rovers to return the obliteration rates of the oldest period. Figure 2 shows the best fit of the whole Noachian terrain crater size distribution with a bi-phase model with constant obliteration rate during each period. In the age system of [2], the average age of Noachian terrains is 3.9 Gy; the terrains would have experienced a period of intense crater obliteration of 4.1 m/my that ended at 3.45 Gy.

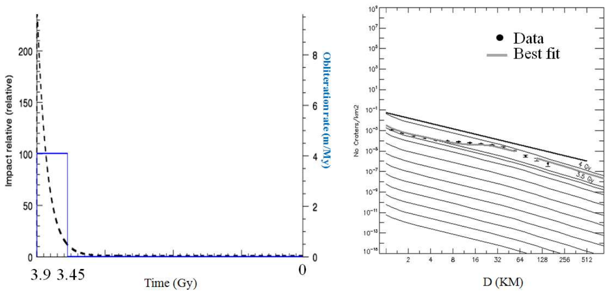

Figure 2: The right graph shows the crater size distribution of all Noachian terrains and the best fit found with a bi-phase model of 2 periods with constant obliteration rate of impact crater. The model is presented on the left.

Data set: We used the global crater data base from [7] that claims to be complete to craters 1 km in diameter and available global Geographic Information System (GIS) maps (e.g., 1:15M geologic maps). Then based on geology and suitable crater populations seen in images, we defined more than a hundred large areas on Mars that were mostly located in Noachian terrains, but several in Hesperian and Amazonian terrains as well (Fig. 3). The areas had to be large enough to have good statistics for impact craters larger than 60 km while located in a coherent geological unit (from 10^5 to 10^6 km^2). Then using GIS techniques, crater size distributions of each area are extracted and used for the inversion.

Results

A part of the modeled eroded crater size distributions failed to generate a satisfactory fit to actual crater populations, particularly in Hesperian and Amazonian terrains, such as the Martian volcanic provinces where punctual resurfacing events may created more complicated crater size distributions that our inversion method would not recognize. However, ~70 sampled areas of Mars returned a satisfactory fit for both bi-phase models (constant and linearly decreasing). The starting ages of these 70 areas range from 4.2 Gy to 2.8 Gy with an average of 3.8 Gy covering the crucial period of early Mars evolution. The ages of the change in the obliteration rate regime range from 3.7 Gy to 1 Gy. There is a clear relationship between the latitude of the studied areas and the age of this change. At high latitudes the old obliteration rate regime lasted much longer until ~1 Gya. In contrast, the equatorial regions experienced a more rapid shift to the current obliteration rate. The values of obliteration rates for Noachian and Hesperian times range from 15m/My to 0.3 m/My. In general, there is a lot of diversity in obliteration histories as can be expect on geologically diverse planet like Mars. However, analyses of our results reveal the crater obliteration rate over time and provide a direct constraint on the climatic evolution of early Mars.

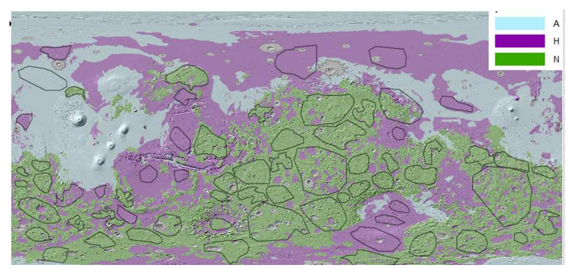

Figure 3: Sampled areas of Mars where the inversion of crater size distribution give a satisfactory fit over the simplified geological map restricted to the 3 major eras (A for Amazonian, H for Hesperian and N for Noachian).

Conclusions

For the first time we have extracted key information about the obliteration rate over time on Mars using crater size frequency distributions from geologically diverse areas. More detailed results describing these rates and its implication for the evolution of the Martian atmosphere will be presented at the conference.

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