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Long-Term evolution of the erosion rates during Early Mars

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Abstract

Many Geologic features attest to the fact that liquid water was once stable on the Martian surface. The erosional processes necessary to create these features must have been supported by a climate that is much different than today. However, the evolution of these primitives conditions toward the current dry and cold Martian climate where the erosion processes are 2-3 orders in magnitude lower represents a major gap in our understanding of the evolution of Mars history.
Here we document the time-dependence of the erosion rates on Mars during early Mars, period during which the erosion rates have decreased of at least one order in magnitude.

1. 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, modified crater or outflows channels ? If so, how long and intense (in term of erosion rates) was this wet period ?

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 Mariner mission times, such processes have been suggested to explain the difference between Martian crater size distributions compared to the lunar ones [3, 4, 5]. In fact, noachian terrains on Mars display a typical S-shape crater size distribution that implies that processes have removed craters as large as 30 km in diameter from the cratering record. To date, no effort have been done to quantify these processes from crater statistics.

Here, we develop 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. Then, we used the model to inverse about 35 crater size distributions extracted from large Martian areas. First, we present the model and the inversion method. Then, we present the results that allow us to constrain the erosion rate evolution during early Mars.

2. Method

The model : To built the model of crater obliteration rate, we used the cratering rate model defined by [6] 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. 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. The model produces a synthetic crater size distribution that integrates both impact cratering rate history and obliteration rate history. We use a simple biphasic models which corresponds to two successive periods during which the obliteration rate has been constant. This model reproduces the S-shape distribution typical of Ancient terrains on Mars.

Inversions: We used a variational 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 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.

Data set: We used the global crater data base from [7] that claims to be complete until 1 km of diameter and all global maps available under Geographic Information System (GIS) environment like the geological map. Then we mapped more than hundred of large area on the Martian surface mainly in noachian terrains but also in hesperian and amazonian terrains. The area have to be large enough to have good statistics for impact craters larger than 60 km while being 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 inversion.

3. Results

About 35 sampled area of Mars returned a satisfactory fit. The starting ages of these 70 areas range from 4.2 Gy to 3.3 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. The values of erosion rates decrease from 6 m/My at 3.8 Gy to 0.6 m/My at 3.2 Gy. Our results indicate that the erosion rate decrease of at least one order in magnitude from at least the middle of Noachian until the end of Hesparian era. Consequently there was a decrease in the efficiency of water-related erosion over this period. These results can be compared to the morphology of the modified impact craters that is depending on the age of the crater [8].

4. Conclusion

We extract for the first time key information looked up in the crater size distributions of large Martian impact crater about the early evolution of Martian atmosphere. Indeed, we document the long term evolution of the erosion rate on Mars from Ancient times with erosion rate at least one order in magnitude larger than today to current low and limited erosion rates.

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