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To cite this version:

A Bouquety, A Séjourné, F Costard, S Bouley, E Leyguarda. Glacial landscape and paleoglaciation in Terra Sabaea: Evidence for a 3.6 Ga plateau ice cap. Ninth International Conference on Mars, Jul 2019, Pasadena (California), United States. hal-04525642

HAL Id: hal-04525642

https://hal.science/hal-04525642v1

Submitted on 28 Mar 2024

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Glacial landscape and paleoglaciation in Terra Sabaea: Evidence for a 3.6 Ga plateau ice cap. A.Bouquety[1], A.Séjourné[1], F.Costard[1], S.Bouley[1] and E.Leyguarda[1], [1]GEOPS-Géosciences Paris Sud, Université Paris-Sud, CNRS, Université Paris-Saclay, 91405 Orsay, France.

Introduction: The early Mars climate is today one of the most debated subject in the martian community [1]. In the one hand, the observation of an early wet and warm climate, carried by the presence of valley network and hydrated minerals, which are best lines of evidence for prolonged liquid water on Mars [2]. The presence of valley networks similar to those on Earth show that during the Noachian (4.5-3.7 Ga), a hydrosphere was active at the surface of Mars with relatively warm and wet conditions. In the other hand, a new vision of an early cold climate, called "icy-highlands" is increasingly considered. This globally sub-zero scenario is carried by climate modelling which indicate that with Noachian/Early Hesperian conditions, namely an atmospheric pressure less than 1 bar, a reduced Tharsis bulge topography and an obliquity of 45° there is a preferential deposition of ice in the southern highlands at high altitude > 1000 m [3,4]. These climate modelling are supported by a geodynamic modelling which indicates that without the Tharsis dome, the valley network would be in a south tropical band from 40°S to 0°, the same distribution as observed today [5]. This tropical band is located in the same area where the ice can settle and accumulate following the climate modeling [4,5,6]. So, following these models, the valley networks could have been formed under a cold climate. Nevertheless, the "icy-highlands scenario" is often questioned, one of the main argument against this scenario is the a lack of geomorphologic evidence of glacial landscapes in Noachian terrains [2]. However, in a previous study, we demonstrated for the first time, thanks to a detailed morphometrical analysis, the presence of glacial landscape in the south of Terra Sabaea at an elevation > 1000 m in two impact craters and one mountain [7]. These glacial landscapes are composed of glacial cirques linked with glacial valleys (Fig. 1). The glacial landscape in Terra Sabaea have the same morphometric characteristics as terrestrial and martian glacial valleys and cirques. They are also very different from those observed in fluvial valleys on Earth and Mars. The purpose of this paper is to study craters in Terra Sabaea using the same morphometric method described in [7] and understand the distribution and type of glacial landscape at regional scale. We performed a comparison between morphologies found in this area and paleoglaciations found on Earth. By studying the morphometry of the valleys, we can define what was the paleo-environnement in the south of Terra Sabaea 3.6 Ga ago.

Data and method: We used Context Camera image (CTX) with a resolution of 6 m/pixel to characterize the valleys on Mars. Then, to constrain their geometry, we used the Digital Terrain Map Reduced Data Record (DTMRDR) data with 1 m numeric height resolution from High-Resolution Stereo Camera (HRSC). We made our measurements using ArcGIS.

Study area: We focus our study on an area at the southwest of Terra Sabaea, between 8°S to 11°S and 31°E to 33°E. This area is one of the highest part in Terra Sabaea with a mean elevation of 3000 m. We can divide the area into three parts based on their relief: (1) the plateau which is wide and sub-flat with a mean ele-

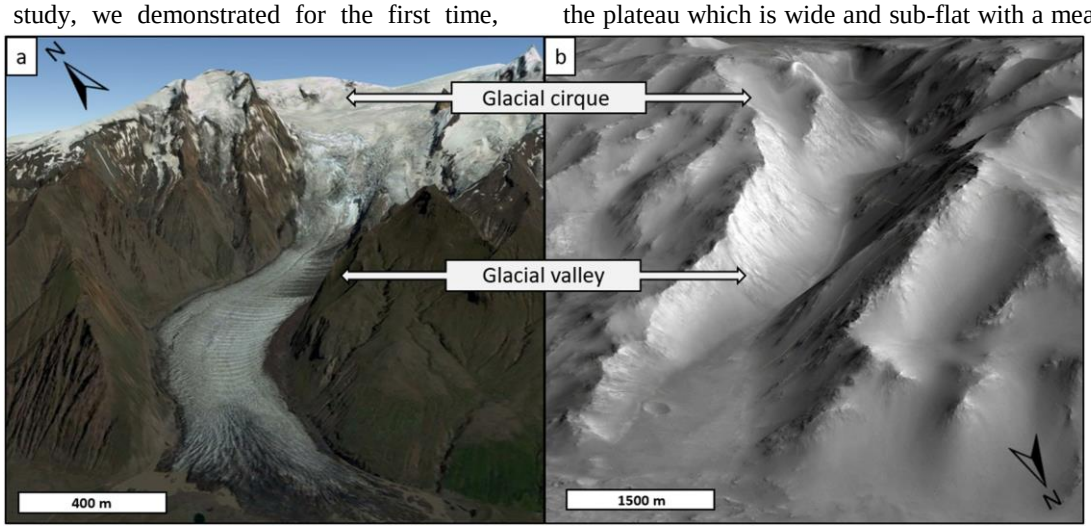

Fig. 1: Comparison between glacial landscapes of (a) the Svinafell glacier in Iceland on Earth and (b) Dawes crater on Mars. Images credit Google Earth

vation of 3150 m, it is the highest zone of the area. (2) 3 large size impact craters on the plateau. These three craters have unmapped valleys on their inner walls. (3) Several valleys flowing downstream radially from the plateau.

Morphometric comparison: The morphometric measurement allowed us to characterized 183 valleys from different locations.

The morphometric analysis revealed that the valleys are similar to terrestrial and martian glacial valleys. In fact, they have a length to width ratio > 1, which is more similar to Dawes crater glacial valleys than to Bakhuysen fluvial valleys which have a length to width ratio >> 1. Their cross-sectional/drainage area ratio are four times larger than Bakhuysen fluvial valleys and similar to the Dawes crater glacial valleys (Fig. 2). On Earth, this value of four is characteristic between glacial and fluvial valleys [8]. Finally, the valleys are at an elevation around 2275 m which is similar to the elevation where we found glacial landscape in a nearby region in Terra Sabaea [7].

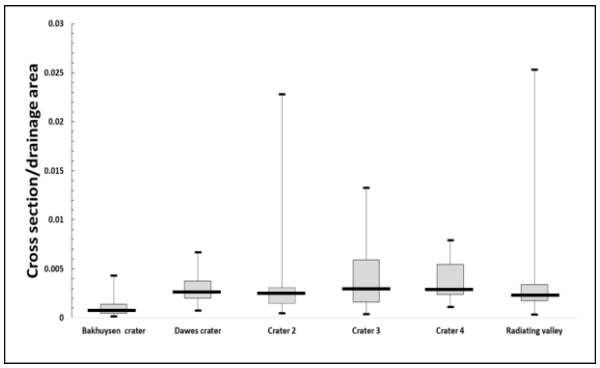

Fig. 2: Box and whisker plot of cross-sectional area/ drainage area for the studied valleys.

Interpretation: On Earth, ice caps are known to be ineffective agents of erosion by their cold-based regime [9,10]. But it had been demonstrated that at the ice cap margin, the erosion rates are much higher than the averaged across the ice cap as a whole and closely resemble at the erosion rate of alpine glacier with surface meltwater accessing the glacier bed at the distance of tens of kilometers from the terminus [10].

By analogy to several sites on Earth (Scotland, Cantal, Tibetan plateau…) we proposed that the glacial landscape in Terra Sabaea was characterized by an erosional polythermal regime where the highest elevation were protected by a cold-based plateau ice cap while, at the margin of this plateau and at lower-altitude, warmed-based alpine glacial valleys flowed radially from the plateau on the slopes and craters inner walls (Fig. 3).

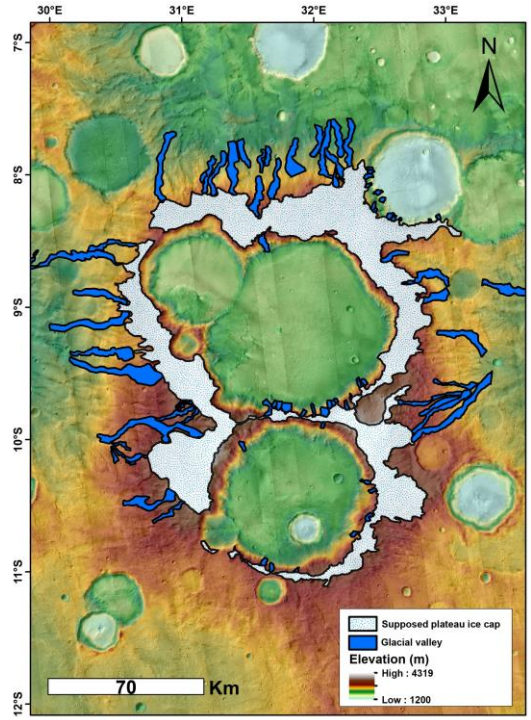

Fig. 3: Distribution of the glacial valleys on the inner walls of Crater 2, 3 and 4 and the supposed plateau ice cap.

Conclusion: The morphometrical analyses allowed us to identified glacial valleys and a supposed glacial ice cap located on a high plateau in Terra Sabaea at an elevation > 2000 m, this glacial landform have morphological and geometrical similarities with glacial landforms on Earth. This study strongly supports the presence of englaced landscape in Terra Sabaea during the Noachian/early Hesperian and adds 71 glacial valleys and a supposed plateau ice cap to the previous demonstrated glacial landscape.

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