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Age and evolution of the lower NW flank of the Hecates Tholus volcano, Mars, based on crater size–frequency distribution on CTX images

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ABSTRACT

We present results of crater size–frequency distribution (SFD) analysis of the lower NW flank of the Hecates Tholus volcano, Elysium volcanic province of Mars, by the use of images acquired by the Context (CTX) instrument on board of Mars Reconnaissance Orbiter (6 m/pixel in resolution). Previous similar works were focused on the caldera complex of the volcano and some sectors of the lower NW flank. In this study, we analyzed the complete crater population of the main geomorphological units characterizing this sector of the volcano (de Pablo, M.A., Centeno, J.D. [2012]. Journal of Maps 8(3), 208–2014), discarding areas with possible clustering to avoid erroneous results. In total, 16 areas corresponding to 10 geomorphological units were measured and absolute model ages were derived for them. The ages correspond to ages of origin as well as of the end of resurfacing events, depending on the analyzed sector, resulting in some cases in more than one age per area.

Our results are in general in agreement with previous works, and establish that the age of the origin of the Hecates Tholus volcano could be at least 3.8 Ga, with possible volcanic eruptions occurring until at least 335 Ma. Glacial events were also dated at 90 Ma, 30 Ma, 16 Ma, and 6 Ma, although it is possible to recognize ages which could also be related to the recent ice ages of Mars, between 2 and 0.4 Ma. Our results allowed us to determine that glacial processes could have been active as far back as 1.4 Ga, with possible events at intermediate ages. We deduced from the resulting ages and our observations on CTX images and the available geomorphological map of the area, that glacial-related processes played an important role in sculpting this flank of the volcano, and the possible level of the glacial sheet at the edge of the main depression of this flank was also deduced, with altitudes ranging between −2035 m and −2490 m, in agreement with the presence of smooth outcrops and roche moutonnées in the area. Finally, a possible evolution of this region of the Hecates Tholus volcano is proposed and discussed, establishing the sequence of the most important geological events which occurred in the area and their possible timings.

1. Introduction

Hecates Tholus (32.12°N, 150.24°E) is a shield volcano of the Elysium volcanic province of Mars, at tropical latitude (Fig. 1). This volcano shows a complex evolution with spatial interaction of tectonic, magmatic and water-related activity (e.g., Mouginis-Mark et al., 1982; Neukum et al., 2004; Hauber et al., 2005; Williams et al., 2005; Fassett and Head, 2006, 2007; Kangi, 2007). The age of Hecates Tholus volcanism ranges between 3800 and 100 Ma, which implies this volcano was active in some way for 80% of the history of Mars (Tanaka, 1986; Neukum et al., 2004; Hauber et al., 2005; Werner, 2009; Platz and Michael, 2011; Robbins et al., 2011). The different stages of the volcano growth on this long-lasting system must therefore have developed within different climatic and regional tectonic settings during the planet's history that could have influenced its evolution (e.g., Baker et al., 1991, 2000 among others). In fact, water had an important role in the evolution of this edifice, indicated, for example, by the clear radial channel network on the flanks of the volcano (Mouginis-Mark et al., 1981, 1982), probably relatively young (Gulick and Baker, 1989, 1990; Fassett and Head, 2006, 2007, 2008), and the magma–water interactions that characterize this region of Mars (e.g., Mouginis-Mark et al., 1981, 1982, 1984; Mouginis-Mark, 1984, 1985). Although some authors have suggested different origins for these channels (e.g. volcanic origin proposed by Williams et al. (2005)), the fluvial origin seems to be the most feasible for

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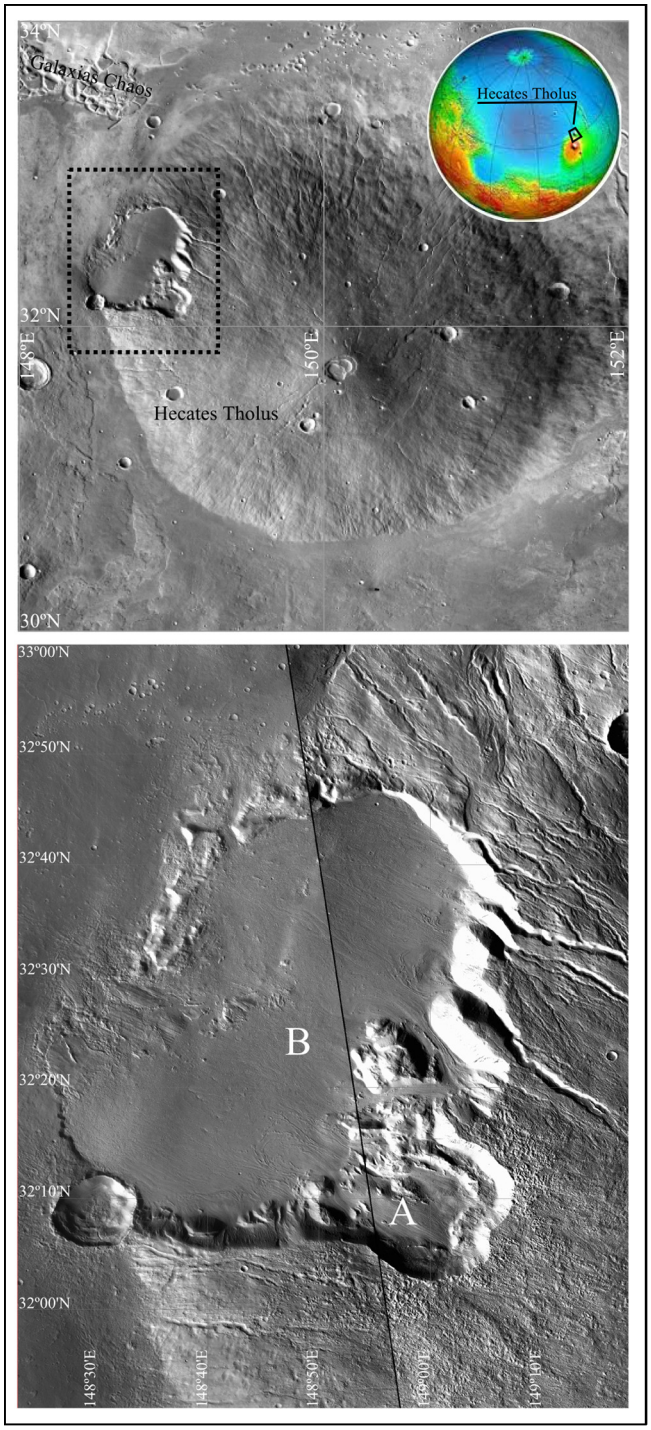

Fig. 1. THEMIS-IR daytime mosaic of the Hecates Tholus volcano of Mars (above), and CTX mosaic of the study area (bottom), the lower NW flank of the edifice. A and B indicate the two depressions which characterize this flank.

most of them, and different possibilities for the origin of the water have been proposed: (1) changes in martian obliquity and redistribution of water equatorward, as revealed by the evidence of glacial landforms located near the martian equator (e.g., Jakosky and Carr, 1985; Jakosky and Haberle, 1992; James et al., 1992; Carr, 1996, 2006; Richardson and Wilson, 2002; Head et al., 2003, 2005; Head and Marchant, 2003; Mischna et al., 2003; Shean et al., 2005); (2) geothermal melting of snow cap on the volcano (Gulick et al., 1997; Zent, 1999; Gulick, 2001; Carr and Head, 2003); (3) remobilization of volatiles during a degassing stage of this volcano (Scott and Wilson, 1999); and (4) basal melting of snowpacks located on the flanks of the volcano (Carr and Head, 2003; Fassett and Head, 2006, 2007,2008).

The glacial origin of these channels by melting of a possible ice-cap or snowpacks has a terrestrial analog at the Antarctic Dry Valleys (e.g., Head and Marchant, 2003). On the other hand, the existence of possible glaciers on Hecates Tholus NW flank and the evidence for glacial retreat to be explained below is consistent with recent glacial activity on Mars (e.g., Neukum et al., 2004; Hauber et al., 2005).

This NW flank of the volcano (Fig. 1) is characterized by a complex structure of nested depressions, one of them at higher altitude that has been interpreted as a peripheral caldera resulting from an explosive eruption ~350 Ma ago (Neukum et al., 2004; Hauber et al., 2005; Werner, 2009). Images acquired by the different cameras on board the Mars Global Surveyor, Mars Odyssey, and Mars Express missions, made it possible to recognize possible glacial features inside those complex depressions (e.g., Neukum et al., 2004; Hauber et al., 2005; Werner, 2009), and to confirm the important role of water and ice in the geological and volcanic evolution of this volcano (e.g., Mouginis-Mark et al., 1982; Mouginis-Mark and Christensen, 2005). For that reason, to conduct detailed studies about the glacial features observed on the volcano, it becomes necessary to refine our knowledge about its glacial and volcanic history, especially when new data are available thanks to the instruments on board the Mars Reconnaissance Orbiter such as the Context (CTX) instrument, which provides images at 6 m per pixel in resolution with a wider spatial coverage than the Mars Orbiter Camera (MOC) and High Resolution Imaging System Experiment (HiRISE) images.

This region was geologically mapped in the global (Greeley and Guest, 1987) and regional (Tanaka et al., 1992, 2005) geological maps of Mars. Recent works also include a more detailed regional mapping (Neukum et al., 2004; Hauber et al., 2005) as well as a 1:100,000 scale geomorphological map (de Pablo and Centeno, 2012) of the western flank of Hecates Tholus. This geomorphological map, based on CTX images and an HRSC-derived digital elevation model, shows a wide variety of glacial-related landforms and features concentrated inside the complex depressions on the lower NW flank, as well as in the surrounding area. However, to establish a geological, geomorphological and climatic history of this volcano from this map requires dating the different terrains of the area, including those possible glacial deposits. For that reason, the objective of this research is to make a crater-size frequency distribution (from here SFD) analysis of the geomorphological units of the lower NW flank of the Hecates Tholus volcano (on CTX images of the area), and to use the results to derive their absolute ages. This work, the most extensive and detailed ever made in this area due to the coverage and resolution of the used data, will complete the first dating works from Neukum et al. (2004), Hauber et al. (2005), and Werner (2009), and provide the necessary information to complete our knowledge about the possible volcanic, glacial, and fluvial evolution of this martian volcano, and about the role played by water ice.

2. Methods

This study is based on the geomorphological map of the lower NW flank of the Hecates Tholus volcano (de Pablo and Centeno, 2012), and we used the mapped geomorphological units to carry out impact crater counts (e.g. Hartmann, 1973, 1984, 2005; Neukum and Hiller, 1981; Neukum, 1983; Neukum and Ivanov, 1994; Hartmann and Neukum, 2001; Ivanov, 2001; Werner and Tanaka, 2011) in order to date those units, using the results to establish the possible evolution of the geological processes that formed