MORPHOMETRY OF GLACIAL VALLEYS AT THE LOWER NW FLANK OF THE HECATES THOLUS VOLCANO, MARS. M.A. de Pablo, Unidad de Geología. Departamento de Geología, Geografía y Medio Ambiente. Universidad de Alcalá. 28871 Alcalá de Henares, Madrid. Spain. (miguelangel.depablo@uah.es).

Introduction: Landforms related to ancient glacial activity has been observed on the flanks of many Martian volcanoes e.g., [1-5], probably as recent as less than 1 Ma, during the last glacial age of Mars [2], [6-9]. However, Hecates Tholus is the unique volcano at the Elysium volcanic province in which those features are visible, such as they were mapped and dated at its NW flank [7-8], [10]. Flutes, roche moutonnees, erratic, moraines, eskers, crevasses, bergschrunds, arêtes, circus or hanging valleys where some of the features described in CTX and HiRISE images of the study area in the lolower NW flank of this volcano (Fig. 1), revealing the existence of an extensive glacial activity until 450 ka [9].

In order to provide more evidences to support the glacial hypothesis of the origin of the mapped and described features in the area, we conducted a morphometrical analysis of the cross sections of a number of valleys dissecting the depression at the lower NW flank of the Hecates Tholus volcano.

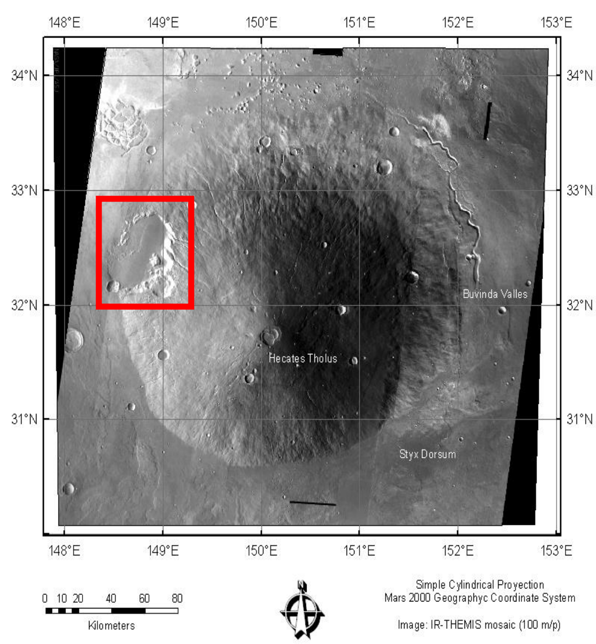

Fig. 1: Location map of the study area (red box) in the lower NW flank of the Hecates Tholus volcano.

Data and methods: The morphometrical analysis of the valleys is based on the use of H1261_0000 HRSC-derived digital elevation model at 12 m/pixel in resolution. We plotted a number of topographic profiles (Fig. 2) by the use of the Geographic Information System (ArcGIS 10.0 by ESRI). We selected 3 topograchic profiles (C1, C2 and C3 on figure 2) dissecting 3 different valleys (1, 2, and 3 in figure 2). Elevation data of each slope of the 3 selected channels were saved into different ASCII files in order to be used to derive the b parameter by the general power law model [11]. Complementarely, FR parameter has been also calculated like total valley width divided by total valley depth. Since those valleys are assymetric, FR parameter for each individual flank has been calculated using the difference between left valley edge (Eld) and elevation of valley floor (Esd) for the left flank, and similarly for the right flank by using the elevation of the right edge (Erd) (Fig. 2). We also used this information to derive height/width ratio used to distinguish V-and U-shaped valleys [12-13] following the equation:

$$Vf = 2Vfw / [(Eld - Esc) + (Erd - Esc)]$$

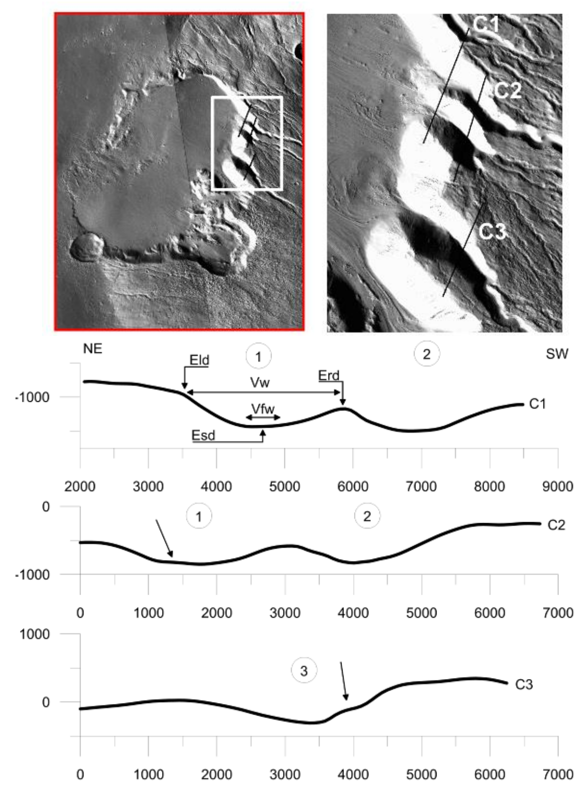

Fig. 2: Study area and location of the 3 cross sections (C1, C2, and C3) of possible glacial valleys (1, 2, and 3). [Vw: Valley width; Vfw: Valley floor width; Eld: Elevation of left edge; Erd: Elevation of right edge; Esd: Elevation of valley floor]. Arrows point to changes on valley flank slope. Vertical exaggeration: x1.

Valleys morphometry: cross sections (Fig. 2) of valleys 1 and 2 are U-shaped (sections C1 and C2). Valley 3 (section C3) shows a less clear U-shape, with higher asymmetry between the flanks of the valley than valleys 1 and 2.

Calculation of valley height/width ratio Vf (Table 1), results on values between 0.5 and 1.2. Since values close to 0 are typical of V-shaped valleys and also more often in regions with deep and linear stream incision [12], we interpretate that the primary origin for those valleys could be fluvial, what is consistent with the proposed origin for most of the valleys dissecting the flanks of Hecates Tholus volcano e.g., [14]. However glacial-related features on the floor of the valleys [10], and the topographic cross sections (Fig.2) also show U-shaped morphologies, although not indisputable. For that reason, a later glacial modification of the valley could be deduced, in agreement with the values close to 1 of Vf (Table 1).

Table 1: Results from morphometrical analysis of topographic profiles,and FR calculation.

Section	C1		C2		C3
Valley	1	2	1	2	3
Eld	-964	-1192	-579	-586	-76
Erd	-1175	-1204	-594	-476	207
Esc	-1436	-1498	-848	-828	-306
Vfw	306	229	302	151	228
Vw	2293	1987	2345	1966	2361
Vf	0,83	0,76	1,15	0,51	0,61
FR_l	0,21	0,15	0,11	0,12	0,10
FR_r	0,11	0,15	0,11	0,18	0,22

On the other hand, *b* parameter (Table 2) ranges between 1.6 and 2.7. Those values are in agreement with fluvial valleys later modified by glacial activity, since low values (lower than 1) are typical of V-shaped valleys. Valley 1 shows the higher values, possibly caused by a higer modification. Moreover in case of valleys 1 and 2, sections near the lower part of the valley result in higher values, what is consistant with a higer glacial erosion near the depression on the lower NW flank of the volcano, meanwhile toward the higher part of the valleys the glacial features are less evident in contrast with the fluvial morphologies. This also agree with the fluvial origin of the channels dissecting the flanks of the volcano e.g., [19]. Those valleys could be excavated by glaciers, resulting on a “Patagonian-Antarctic” erosive model (Fig. 3), consistant with the existence of extensive glaciers n the area [9, 10].

Table 2: Results from general power law fitting [16]to the elevation data of 3 valleys.

Section	C1		C2		C3
Valley	1	2	1	2	3
a	4,58E-05	1,25E-03	2,61E-04	5,82E-03	9,33E-04
b	2,26	1,80	1,96	1,58	1,83
x()	1,25E+03	9,52E+02	1,17E+03	8,86E+02	9,70E+02
y()	5,70E+02	4,94E+02	1,15E+03	1,17E+03	1,71E+03
R^2	0,982	0,986	0,989	0,994	0,979
RMSE	17,678	11,931	9,190	7,565	20,772
A=LN(a)	9,992	6,687	8,250	5,14635	6,978

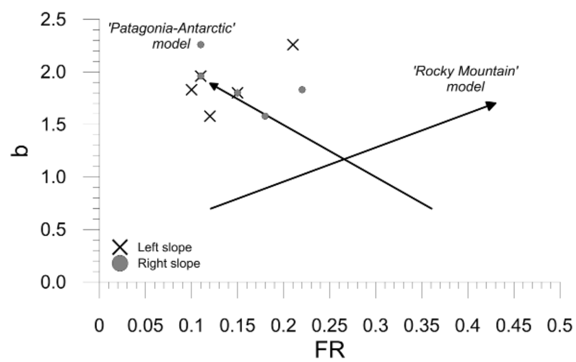

Fig. 3: b-FR plot [15]of the studied valleys on Hecates Tholus volcano.

Conclusions: Althought more analysis are required, this preliminary analysis allowed to propose that the origin of the main valleys (those studied) rising the lower depression in the lower NW flank of the HecatesTholus volcano had a fluvial origin although they were later modified by large glaciers, in agreement with many previous geological studies of the area.

References: [1] Head et al., 2004. *Geophysical Research Abstracts*, 6. 07937. [2] Head et al., 2005. *Nature*, 434. 346-351. [3] Milkovich et al., 2006. *Icarus*, 181(2). 388-407. [5] Shean et al., 2005. *J. Geophys. Res*., 110. [6] Head, et al., 2003. *Nature*, 426. 797-802. [7] Neukum et al., 2004. *Nature*, 432. 971-979. [8] Hauber et al., 2005. *Nature*, 434. 356-361. [9] de Pablo et al., 2013. *Icarus*, 226. 455-469. [10] de Pablo and Centeno, 2012. *Journal of Maps*, 2012. 8(3) 208-214. [11] Pattyn & Van Huele 1998 Earth Surf.e Proc. & Landforms 23: 761-767. [12] Bull & McFadden 1977 Geomorphology in Arid Regions. [13] Pedrera et al. 2009 Geomorphology, 105. [14] Fasset & Head, 2006. Planet. & Spa. Sc., 54. 370-378. [15] Hirano & Aniya 1988 Earth Surf. Proc. Landforms, 13 707–716.