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KARST LANDFORMS IN A MARTIAN EVAPORITIC DOME

KRAŠKE OBLIKE POVRŠJA NA MARSOVI EVAPORITNI DOMI

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Abstract UDC 911.2:551.435.8:523.43
Davide Baioni, Nadja Zupan Hajna & Forese Carlo Wezel: Karst landforms in a Martian Evaporitic Dome
The Tithonium Chasma is the northern trench of the western troughs of Valles Marineris (Mars). In the eastern part of the canyon system a mountain displaying a dome shape morphology is located. According to OMEGA mineralogical data (OMEGA data orbit 531_3) and further studies the dome appears to consist of magnesium sulphate (kieserite), an evaporitic mineral also found on the Earth. Previous works highlighted the presence of karst-like landforms and morphologies that strongly resemble the evaporitic karst morphologies found on the Earth. Through the analysis of the new MRO HiRISE images we have investigated the Martian landform and the possible processes involved in their formation and shaping in great detail. The analysis carried out show that the landforms observed clearly indicate the presence of solutional processes that also acted in a selective way, highlighting that the Martian dome can be formed of different materials (minerals, grain-size, ect.) with different solutional properties. The results of our observation also suggest that on the dome liquid water must have existed in the past for enough time so that the solution features we investigated could be formed.
Keywords: Mars, kieserite, dissolution, karst features.

Izvleček UDK 911.2:551.435.8:523.43
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Tithonium Chasma je severni jarek zahodnega dela kanjona Valles Marineris (Mars). V njegovem vzhodnem delu leži gora, ki kaže značilno kupolasto obliko dome. Mineraloški podatki pridobljeni z OMEGA spektrometrom (podatki OMEGA orbit 531_3) in nadaljnje študije kažejo, da doma sestoji iz magnezijevega sulfata (kizerit), evaporitnega minerala, ki ga najdemo tudi na Zemlji. Predhodne raziskave dome poudarjajo prisotnost krasu podobnih oblik in oblik, močno podobnim oblikam evaporitnega krasa na Zemlji. Z analizami novih posnetkov MRO HiRISE smo raziskovali izbrano Marsovo površino in predvideli možne procese, ki bi lahko imeli pomembno vlogo pri njenem nastanku in oblikovanju. Opravljene analize so potrdile, da opazovane oblike površja jasno nakazujejo prisotnost procesov raztapljanja. Iz oblik se da sklepati tudi na prisotnost selektivne korozije, ki pa tudi nakazuje, da doma sestoji iz različnih materialov (minerali, zrnavost, itd.), ki se drugače obnašajo pri raztapljanju. Rezultati naših opazovanj tudi nakazujejo, da je na domi nekoč morala obstajati tekoča voda in to dovolj časa, da so korozijske oblike lahko nastale.
Ključne besede: Mars, kizerit, raztapljanje, kraške oblike.

INTRODUCTION

During the morphological investigation of a Martian evaporite (magnesium sulphate) dome located on the bottom of the Tithonium Chasma (TC) canyon a karst-like topography characterized by depressions of various sizes and shapes, solution valleys and other karst-like features were detected (Baioni & Wezel 2008). The authors have chosen to use the term karst-like because the landforms observed on the dome surface strongly appear

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to be karst landforms but it was not possible to establish clearly the nature of the processes which were involved in their formation and shaping. For some of the landforms observed the images available were not useful to understand clearly if they were made and shaped totally by solutional processes like the karst landforms on the Earth or by other processes as happen in the pseudo-karst landforms on the Earth.

On the Earth the karst features are formed in carbonate and evaporite rocks such as gypsum and salt due to their solution and with the establishing of subsurface water drainage and genesis of caves and characteristic surface forms. Karst-like features which are produced by processes other than solution-induced subsidence and collapse are called pseudo-karst features (in lava flows, glaciers; features formed by the thawing of ground ice and piping; e.g., Ford & Williams 1989).

On Mars pseudo-karst and karst landforms with caves were already hypothesized. Schaefer (1990) suggested that the 'thumbprint' terrains noted by Guest *et al.* (1977) in high-resolution Viking Orbiter photographs of the northern plains of Mars were formed due to differential solutions of large carbonate deposits located in low-lying areas and that its morphology might be an analogue of the arid karst of Australia's Nullabor Plain. Karst-like topographies were described in some regions of Mars by Berczi (2005) and Preuschmann *et al.* (2006) and Martian analogues of Terrestrial pseudo-karst were mentioned by Malin and Edgett (2000) and were discussed by Halliday (2004). Authors reported several Martian features as analogues to terrestrial pseudo-karst features like tall caves which can be developed in detected talus accumulations, then open conduits above them which may be analogous to terrestrial piping caves. Extraterrestrial caves were also hypothesized and discussed by Boston (2004). On Mars she predicted the existence of pseudo-karst caves as tectonic caves, lava tubes, piping caves (formed by seasonal or longer-term cycles of thawing ect.) and hypothesized the carbonate formation and their karstification. Planetary Science Institute (2005–2008) is running the project with the title Pseudo-karst on Mars: the evolution of the Hephaestus Fossae and Hebrus Vallis System, Utopia Basin (Planetary Sciences Institute 2008).

The aim of this paper is to understand, through the analysis of the new MRO HiRISE images now available, if the karst-like features observed in the evaporite dome in the Tithonium Chasma are true (real) karst due to solution-induced subsidence and collapse processes or are pseudo-karst due to other, different processes. In fact, because the high resolution of the new images available of the Martian surface, the processes formatting the karst-like features in the dome might be hypothesized as well as the origin by dissolution of the sulphate rocks of the landforms observed might be envisaged from their appearance, shape, size and disposition.

STUDY AREA SETTING (GEOLOGY AND MINERALOGY)

The Tithonium Chasma (TC) is comprised in the Valles Marineris troughs, a rift system that belongs to the Tharsis radial pattern of fractures (Carr 1981). The trough is located near to the Martian equator, stretching about 850 km along an E-W direction (Fig. 1A).

The TC canyon (Fig. 1B) cuts through the surrounding plateau of Hesperian age (Scott & Tanaka 1986) displaying a depth of around -2,600 m relative to the average Martian MOLA radius datum. In the western part it is characterized by a wider opening with bigger depths than in the eastern one. From the western side the canyon becomes narrower eastward, forming another chasma-like depression. The western part of the TC forms a linear trough and may be interpreted as graben structure, in which a recent tectonic activity occurred only on the northern wall, while the other parts of the trough show a morphology that seems to be primarily related to erosional processes and secondarily to tectonics (Peulvast *et al.* 2001).

The chasma walls display numerous finger-shaped side canyons created by groundwater sapping and high slope angles (up to 40°) indicating that they consist of consolidated material. The TC floor is not smooth but rugged and it also displays areas where is covered with landslide debris or is cracked by movements along the faults, suggesting that the topography was produced by the floor subsidence. The eastern part of the TC is 150 km wide and over 6 km deep. Its evolution was dominated by geomorphological processes similar to those responsible for the scalloped troughs (Tanaka & Golombek 1989). Here, landslides have enlarged the chasma walls and created hummocky debris deposits on the floor. The trough floor shows impact craters, some sets of lineaments, which might represent tectonic fracture systems, and wind related morphology.

At the eastern end of TC (at about latitude 5° S and longitude 280° E) on the floor of the TC, spectra taken with the OMEGA spectrometer provide evidence of sul-

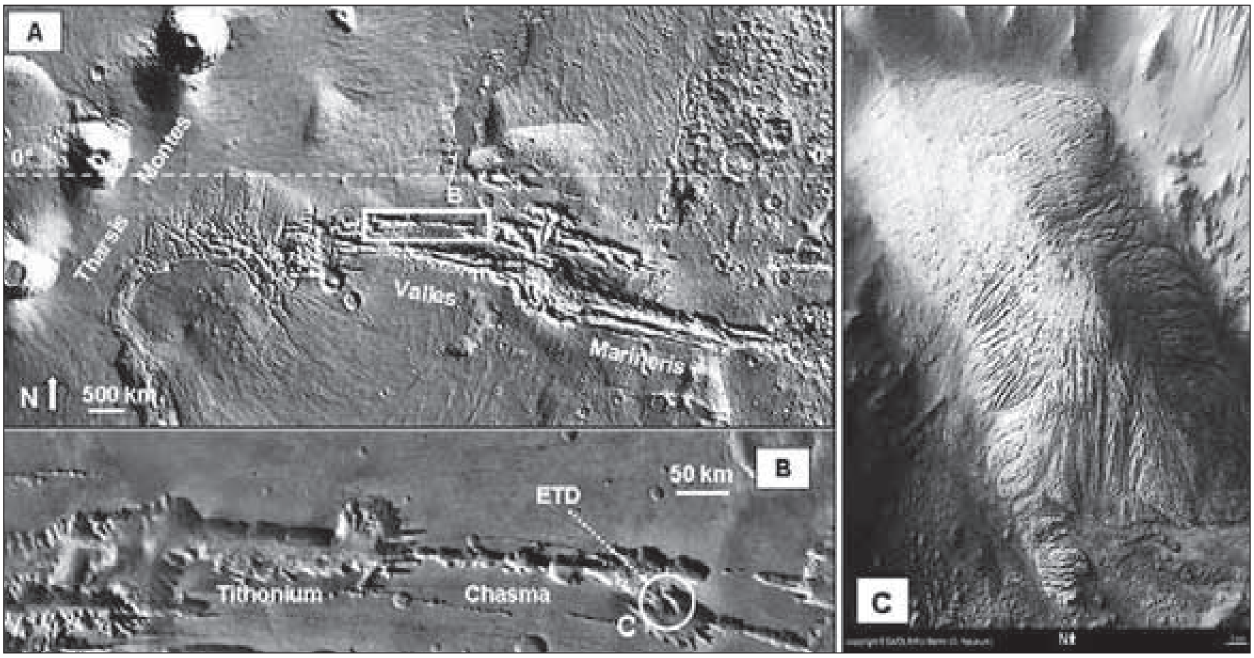

Fig. 1: Valles Marineris, Mars. A: Location of Tithonium Chasma (TC), Mars (white box). B: Image of Tithonium Chasma, showing the magnesium sulphate dome (ETD) at eastern side marked by white circle. C: HRSC image of the ETD. Images were taken by European Space Agency (ESA) Web site (http://www.esa.int., ID number: SEMLGXXEM4E).

phate minerals associated with bright interior layered deposits (ILD). The unit shows the dome shape morphology and it is now proven to bear magnesium sulphate (Bibring *et al.* 2006) and is below referred as the East Tithonium Dome (ETD; Fig. 1C).

The dome rises from the chasma floor to an altitude of about 3,400 m and shows an elongate, elliptical plane shape. The longest axis displays a NW-SE trend with a length of about 23.5 km, while the widths vary between 10 and 14 km. The crestal region (2,550 m to 2,750 m) lies in the central part of a moderate vaulted summit plateau, about 7 km long, that displays a very gentle slope of about 6 %, and is surrounded by steep slope flanks. The dome shows the asymmetric flank topography, with the western and southern sides that generally have steeper slope. The main flank slopes range between 8 % and 33 % and they are quite similar only in the central part of the dome, while they are different in all the other parts.

The mineralogical characteristics of the ETD have been indicated by the OMEGA image spectrometer data that mapped it as a sulphate deposit (OMEGA data orbit 531_3) (Bibring *et al.* 2006). Further studies on the spectral characteristic absorptions for the hydrated magnesium sulphates carried out on the deposits within the TC (Popa 2006), showed the mineralogical components displayed by the ETD in detail. According to these results the ETD shows clear signatures of kieserite ($Mg\ SO_4.H_2O$) which are intensified on the western side (Popa 2006; Popa *et al.* 2007a, b; Popa *et al.* 2007).

The ETD cannot be constituted entirely by kieserite alone, and the kieserite displayed on the surface does not represent the main dome material, but could only be the result of surface alteration processes of the subsurface material. It could be represented by the same salts that on the Earth alter to kieserite (Baioni & Wezel 2008).

KARST LANDFORMS ANALYSIS ON THE EAST TITHONIUM DOME

ETD MORPHOLOGICAL ANALYSIS

The ETD's features have been investigated in detail using HRSC, MOC and in particular MRO HiRISE data, while the morphometric characteristics have been measured on a topographic map (50 m contours lines) created using HRSC and MOLA data.

The dome flanks are characterized by deep gullies that display a radial system which develops from the margins of the summit plateau (Fig. 1C). The morphology of the gullies seems to show few differences that can be observed especially in the southern part, where the dome flanks are heavily eroded. Some parts, as in the southern flank of the dome, display aligned gullies that are characterized by a straight course and with V-shaped walls (Baioni & Wezel 2008), while other parts display gullies characterized by steep walls on both sides but a wider and shallower bottom.

Depositional forms are present at the foot of the slopes, while they seem to be lacking along the dome flanks. Deposits showing a lobate morphology are found at the base of the flanks. On the south-western corner of the dome, fan systems of multiple lobe-shaped deposits can be observed. On the western side of the dome a deposit that appears to display periglacial rock glacier features (Marchant & Head 2003) such as, tongue shapes, steep sides and fronts can be seen (Baioni & Wezel 2008). Solifluction lobes can be observed at the south-eastern corner of the dome. These display arcuate-shaped ridges and are thought to be due to very slow movements.

The features of gully system and of down-slope deposits, that are indicative of a viscous flow, are thought to be connected to a slow flowage motion probably caused by the partial melting of interstitial ice in a periglacial environment, or permafrost rich soil, suggesting that either the material is ice-rich or has been at one time.

KARST FEATURES

Features created by fluvio-erosional and solutional processes are well visible on the ETD (Fig. 1C, 3A). The solutional surface is characterized by landforms typical of the karst morphology such as, karren, dolines, collapse dolines and entrances to the shafts. Features which are common for karst of the high mountains on the Earth (Ford 1983; Klimchouk *et al.* 2006) and the presence of step-like leveled surfaces along dome flanks, such as on the summit plateau (top of the dome) can also be observed.

Karren-like features

Karren is the common term used for dissolution features on exposed soluble rock surfaces that can be formed and found in many different kinds of its shapes (Ford & Williams 2007). Karren are formed when water runs down a sloping rock surface, dissolving the rock while it runs. On the Earth two basic processes control their formation, the dissolution by thin water films flowing down inclined surfaces and the dissolution kinetics of the CO_2-containing rainwater (Dreybrodt & Kaufmann 2007). On Mars the occurrence of rainwater has been only proposed in Noachian and partially in the Hesperian age (Baker *et al.* 1991) and locally in the early Amazonian (Gulik & Baker 1989). Considering that on the ETD there are not impact craters and that the evaporite karst landform are well preserved, we presume that the ETD is quite young and it can not be older than Amazonian age. Considering the presumed absence of rainwater on Mars postdating the early Amazonian, we suppose that the necessary liquid water for stimulating the dissolution processes was probably provided by the melting of frozen groundwater or ice.

Different types of karren are well expressed in the dome slopes where long linear and many polygenetic karren, which are mixtures of different karren forms, can be observed. *Long linear karren* were detected on the western flank of the dome, where long solution runnels of about 100 m are visible also next to a shaft wall (Fig. 2A). From their position and size we suppose that they were formed as hydraulically controlled karren (in sense of Maire 1999, 2004). *Polygenetic karren forms* of different sizes such as, heelprints, arcuate headwalls, flat floors open in down slope direction and pans were found on the dome surface.

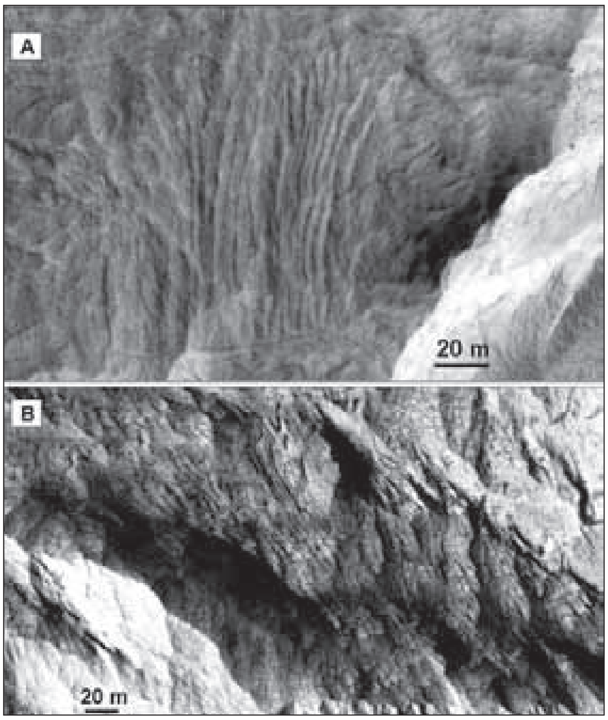

Fig. 2: Solutional surfaces. A: Linear karren developing along the slope in the western flank of ETD (MRO HiRISE image PSP_007153_1745; north upward). B: Solutional karren located in the north-eastern flank of ETD showing grapes-like shape (MRO HiRISE image PSP_004951_1745; north upward). Images were taken by HIRISE Web site (http://hirise.lpl.arizona.edu).

On the western flank of the EDT some particular surface landforms, which we named "grape-like" karren (Fig. 2B) can be observed. Patterns of *grape-like* forms are actually covering the bottoms of the depressions in *box-work-like* form (Fig. 3). The elongated wide ridges display more or less smooth surfaces and between two of the longest ridges *stepped pavements* often covered by tracts of karren (grape-like and clint-and-grike topography; Figs. 3A, B, B1, C) can be observed (Figs. 3A, B, C). The whole pattern

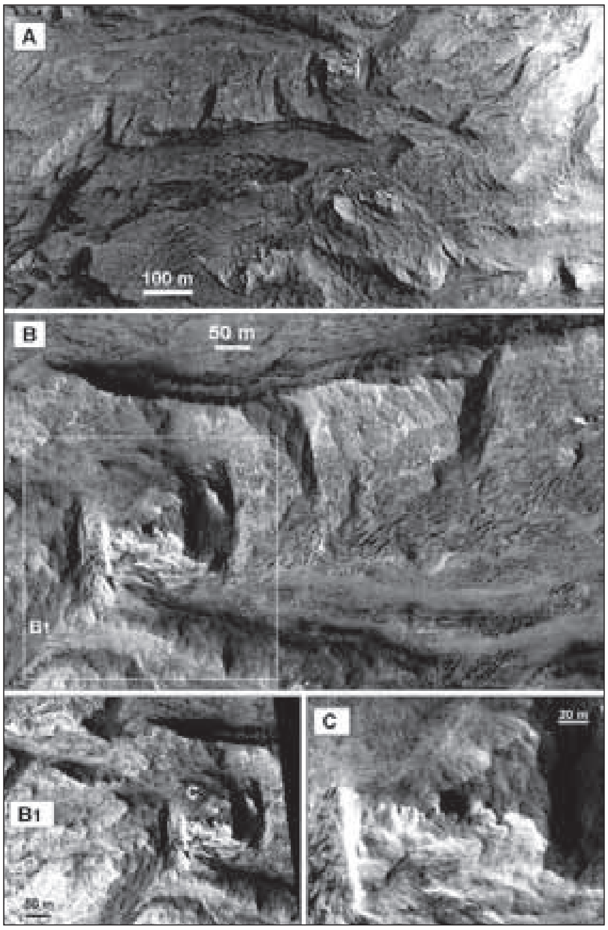

Fig. 3: Fluvio erosional/corrosional surfaces. A: Step like elevated surfaces along the flank slope (north downward). B, B1, C: Solutional features in the north-eastern flank of the ETD. Solution karren forming grape-like shapes are formed in the bottoms of the depressions between jut out ridges (B1) (north upward). Images show depressions with different sizes and elongate or rounded (C) shapes (north upward). (MRO HiRISE image PSP_004951_1745). Images were taken by HiRISE Web site (http://hirise.lpl.arizona.edu).

was probably formed by selective corrosion processes due to the different mineral composition, or to the presence of different sizes of the crystals of the same mineral, or to the presence of areas with a different porosity of the bedrock.

In some parts of the dome surface ripple-like flutes can also be seen. We suppose that these morphologies could have been formed as the result of the air drift (wind), rather than by water flow.

Dolines and polygonal karst

Williams (2004) wrote that the bowl-shaped form of a doline indicates that more material has been removed from its centre than from around its margins. Where the principal process is dissolution of the bedrock we are talking about solution dolines, whilst where the main process is the collapse above underlying caverns we are talking about collapse dolines. The development of dolines depends on the ability of water to sink into and flow through the bedrock and that ability is characteristic for karst.

Rounded depressions of different sizes were detected in the ETD surface (Fig. 4). For some of them as for

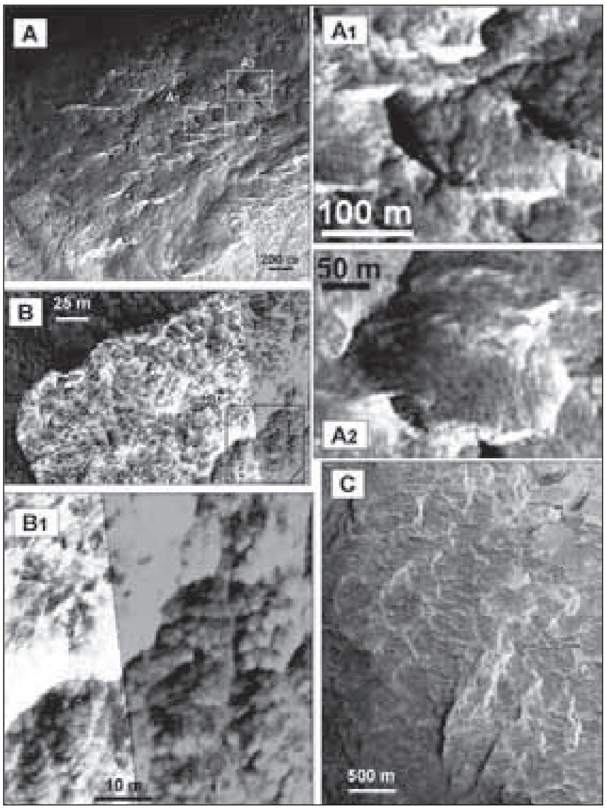

Fig. 4: Doline-like features. A: Polygonal karst landscape in the north-eastern part of the ETD (MRO HiRISE image PSP_007153_1745; north upward). A1, A2: Doline features located in the north-eastern part of the EDT. B: Polygonal karst landscape in the north-western part of the ETD (MRO HiRISE image PSP_007153_1745; north upward). B1: Area showing dolines occupying almost all the space resembling an egg-box like topography. C: Polygonal karst landscape in the plateau area of the ETD showing the divides between adjoining depressions (white rounded) forming a cellular mesh pattern (MRO HiRISE image PSP_004951_1745; north downward). Images were taken by HiRISE Web site (http://hirise.lpl.arizona.edu).

the small solution holes we can not anticipate the genesis, whilst for some of them we suppose that they are solution dolines and they were not built or shaped by other processes such as, wind erosion, or impact craters heavily eroded or reworked by geomorphic processes.

In particular for the smaller holes observed in the surface we are not able to establish if they are dolines or pits, because even in the MRO HiRISE images they appear too small in diameter and the shadow on the images is too strong, to allow us to understand it. These rounded, shallow depressions are located in almost every part of the dome and their location and shape seem to be unrelated to the surface slope or bedding plane. We suppose that if these landforms are really pits, they could be interpreted as *rock-holes* (Jennings 1985; Neuendorf *et al.* 2005), while if they are not pits, they may be just solution dolines much smaller in size than the other closed depression landforms observed.

Bigger depressions which we interpreted as *solution dolines* can be observed on the dome surface. Dolines can occur as scattered isolated individuals or as densely packed groups (Ford & Williams 2007). In the ETD some individual solution dolines can be observed in the north-eastern part where they display diameters of up to 200 m.

Polygonal karst landscapes can be observed in the ETD surface. Where dolines totally pock some parts of the surface and occupy almost all the space, we are dealing with typical polygonal karst (Williams 1972; White 1988; Ford & Williams 2007). Polygonal karst viewed from the top of the landscape, resembles an egg-box-like topography. Landscapes displaying polygonal karst-like features can be found in the part of the ETD characterized by lower inclines of the slope, such as, the north-western part, the down slope area in the north-eastern part and in the summit plateau (Fig. 4). In the north-eastern part of the ETD polygonal karst (Fig. 4A) covers an area of about 2.5 km^2 and displays deep and well marked depressions characterized by sharp divides and are over 100 m in diameter (Figs. 4A1, A2). In the north-western part the polygonal karst (Fig. 4B) cover an area of about 1.5 km^2. Here the depressions appear shallower and show smaller sizes that range from a few meters to almost 10 m in diameter (Fig. 4B1). In the summit plateau the polygonal karst (Fig. 4C) can be observed mainly in central part, covering an area of about 4 square km. Here the depressions show a bigger size in diameter that range between 200 m to over 500 m. It can be seen that especially in the summit plateau and in the north-western areas the divides between adjoining depressions form a cellular mesh pattern just as typically happens in the evaporite terrains on the Earth (Ford & Williams 2007).

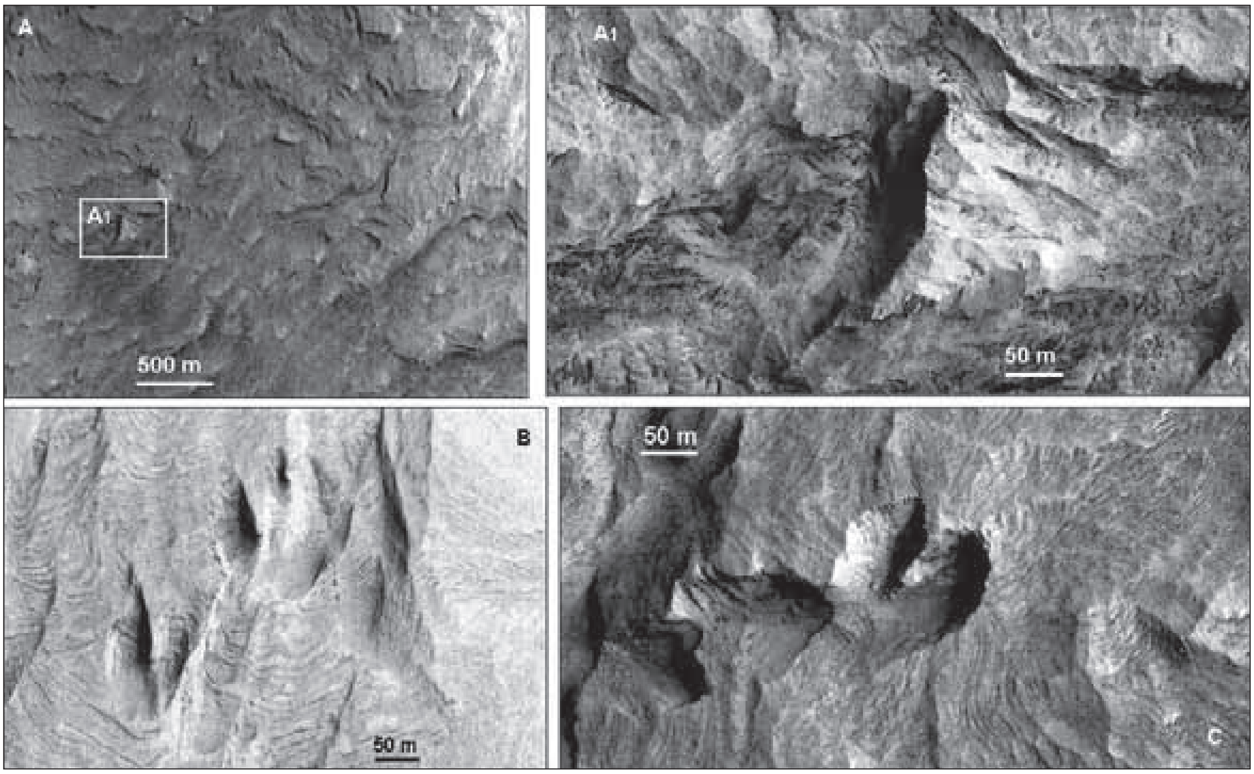

Fig. 5: Collapse dolines. A, A1: Collapse doline located in the north-western flank of the ETD (MRO HiRISE image PSP_004951_1745; north downward). B, C: Collapse doline located in the upper part of the eastern flank of the ETD, next the margin of the plateau area (MRO HiRISE image PSP_004951_1745; north downward). Images were taken by HiRISE Web site (http://hirise.lpl.arizona.edu).

Collapse dolines

On the Earth the collapse doline is a karst feature formed by collapse which was preceded by dissolution of the karst rock, which forms a void into which material can fall (Williams 2004). Where the collapse dolines form in karst bedrock the void is commonly part of a cave system.

Collapse dolines of various sizes can be found mainly along the flanks of the ETD (Fig. 5). The depressions observed are bowl-shaped (Figs. 5B, 5C) or with an elongate shape (Fig. 5A), wide at the top and narrow at the bottom, or mostly drop-like shaped that strongly resemble those found on the Earth. These landforms also appear to be located on alignments along the slope direction, displaying depression surfaces characterized by elongate shape steep side walls and flat floors, as can be observed in the upper part of the south-western flanks (Figs. 5B, 5C). From the observation that we made we are not able to detect the collapse mechanism clearly, while we suppose that the collapsed material missing in some case (Figs. 5B, 5C) has been removed in the beginning by water erosion and successively by wind erosion.

Caves

On the Earth cave development in open evaporite domes (salt or sulphate rocks are exposed to the surface) is characterized by the formation of linear or crudely dendritic caves, which commonly carry sink streams. Where the vadose zone is thick, vertical shafts continue as single sub-horizontal passages, leading to the outlets at base level (Klimchouk 2004).

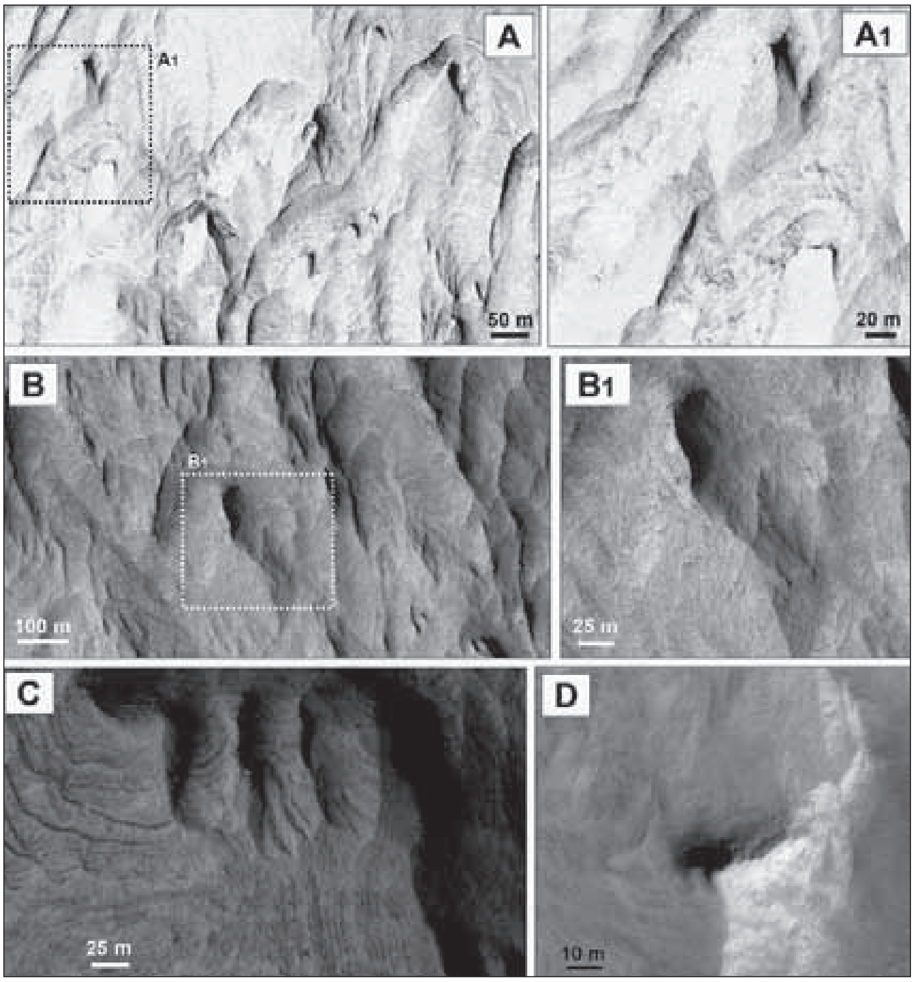

Fig. 6: Outflow caves. A, A1: Several outflow caves are located in the southern flank (upper part) of the ETD (MRO HiRISE image PSP_004951_1745; north upward). B, B1, C: Outflow cave located in the southern flank (middle part) of the ETD (MRO HiRISE image PSP_004951_1745; north upward). D: Outflow caves located in the western flank of the ETD (MRO HiRISE image PSP_007153_1745). On the slopes below the cave entrances erosional features are well expressed. Images were taken by HiRISE Web site (http://hirise.lpl.arizona.edu).

The analysis of the Martian images highlights that on the ETD slopes it is possible to observe the presence of entrances to caves, to the vertical and to the outflow caves. Of course, the interior of the caves and connections between shafts and outflow caves cannot be seen and it will remain unknown until the day the first Martian speleologists enter these caves.

Landforms that we interpreted as possible shafts entrances can be observed on the ETD, especially in the upper part of the western flank and in the southern flank. We observed more than one hundred of deep depressions, located on the dome slopes. The bottoms of the depressions, where the entrances to the possible *shafts* could be located, often cannot be seen, because of the strong shadow; but erosional features (water channels) leading towards the bottoms can be seen (Figs. 2A, 3B, C). The presence of the erosional features on the depressions slopes, allow us to suppose that these deep depressions in the ETD might end with vadose shafts, which could be formed by sinking water probably due to ice melting.

On the southern flank of the ETD many of the cave entrances located on the steep slopes can be observed (Fig. 6). Above the caves and along their sides the rims of bedrock display erosional/corrosional characteristics probably produced by flowing water (Figs. 6A, A1). The entrances observed generally display sizes up to 50 m in diameter. The analysis of their location and of the outflow features are probably produced by flowing-water and/or bedrock material in the dome slope below (Figs. 6A, B, C, D), highlights characteristics of typical *outflow caves*. On some of the walls below the possible entrances, U-shaped karren up to 0.5 m in diameter can be seen (Fig. 6C).

No cave entrances (outflow caves) or ponors were detected at the base of the ETD in the border line between the chasma floor and the ETD unit.

DISCUSSION AND CONCLUSIONS

There are many existing definitions of karst (cited by Ford & Williams 1989, 2007) from which, it can be concluded, that three fundamental conditions must be present for karst formation: soluble rock, water and development of subsurface water drainage. We have to emphasize that karst will only evolve if water can get underground and dissolve caves, which provide conduits for the evacuation of material in solution from the surface and/or from near the surface (Ford & Williams 2007).

In the ETD the existence of evaporite minerals with karst-like landforms, and a surface exposure to water (as witnessed by the observed landforms), which are base for prediction of karst processes as is dissolution, were already detected by Baioni and Wezel (2008).

We have to consider that on the Earth evaporite karst features can form much more rapidly (a matter of days, weeks, years) in comparison with the formation in the carbonate rocks (Johnson 2008). The velocity of dissolution and formation of karst features is connected to the high solubility of evaporite minerals. At 25°C the solubility of gypsum is about 2.4 g/l, of halite about 360 g/l and of kieserite about 860 g/l in the comparison to calcite with 0.05 g/l (University of Bremen 2008). The solubility of kieserite, which was detected on ETD, is up to 2.5 higher than halite. The evaporite rocks may dissolve at very high rates if they are in the contact with under saturated water (Klimchouk 2004). We suppose that the ETD was acting probably as an open evaporite dome in arid and semi-arid environments just as on the Earth (Iran, Israel, Algeria, etc.) when water is available. The karst development on the open evaporite domes is strongly connected with the existence of flowing water that can be valid for both the Earth and Mars.

In the Martian ETD we can suppose that probably the melting of ice might have driven the processes of solution and/or collapse on the evaporite rock just as on the Earth. In fact, it is well known that dissolution may occur also on ice-covered terrain of the Earth, where the ice does not continuously touch the surface of the rock. In these conditions on the Earth it is common that different kinds of karren may be developed, just as we observed on the ETD surface.

The images and the data studied seem to highlight that:

(i) The karst-like features detected by Baioni & Wezel (2008) appear to be true karst features existing on the ETD surface. The landforms observed clearly indicate the presence of solutional processes and that are not due to thermokarst processes.

(ii) The landforms observed display solution and corrosion processes acted in a selective way, highlighting that the dome is constituted by different lithologies and/or minerals with different solubility proprieties. The observation of the edges of different erosional features in the ETD, appear sharper than those we can be found on the Earth salt domes. This characteristic perhaps could be due both to the presence of different minerals that outcrop on the ETD surface (kieserite has more expressed cleavage than salt) and to the action of erosive wind processes.

(iii) The presence of dolines as an index landform of karst (Ford & Willimas 2007) and shafts indicates the presence of flowing water. Intense surface dissolution which probably existed during ice-melt and intense runoff along the ETD slope produced erosional/solutional features. On the ETD liquid water had to exist for enough time so that solution features could be formed. Considering the characteristics of the evaporite karst and their rapid evolution, the landforms we observed allow us to suppose that there has been just one episode with available water (geologically short ”cool-wet episode”) and after which there was no more water and thus karstification processes finished. The process was probably short-lived and lasted for a very short period.

(iv) The lack of karst springs or outlet caves at the base of the dome and on the borderline between ETD and the chasma floor, might highlight that an amount of available water under the ETD surface penetrated below the chasma bottom. We can hypothesize that the water probably flowed through roots of the ETD under the basalt covering the chasma floor.

(v) In one period of Martian history, probably in the young Amazonian age, there has been enough liquid water to create different kinds of karren in the soluble rocks, that we think mainly represented by salt, of the ETD. This allows us to suppose that at some time the past Martian atmospheric conditions were much different from now and probably a drastic change ocurred.

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