

## MORPHOLOGICAL AND MINERALOGICAL ANALYSIS OF EAST CANDOR CHASMA IN VALLES MARINERIS ON MARS.

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**Introduction:** East Candor Chasma is one of the large Valles Marineris chasmata (Figure 1). It is bounded by walls more than 6 km high displaying the initial spur and gully morphology, locally reworked by mass wasting processes [1]. The canyon is filled with layered deposits (Interior Layered Deposits -ILDs-), for which several origins have been proposed including volcanic [2, 3, 4], aeolian [5], and lacustrine [5, 6]. Ferric oxides and sulfates are detected in several places [7, 8, 9] and their occurrence may constrain the role of water in the geological history of Valles Marineris. In order to characterize the geomorphology and evolution of the area, MOLA DEM, HRSC, THEMIS, MOC and HiRISE images are interpreted, and compared to mineralogy as obtained previously [8-9].

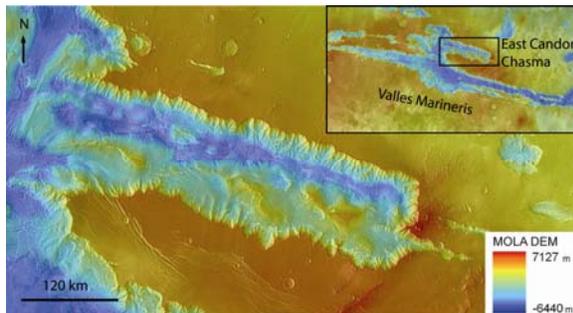


Figure 1: East Candor Chasma region (63.5°W-72°W, 5°S-9°S). MOLA topographic map overlapping a mosaic of THEMIS IR images. ILDs are surrounded by the dashed line.

**Datasets and methods:** We use several datasets that are exposed on Table 1. These datasets have been combined into a geographic information system using the Mars 2000 geographic coordinate system available in ArcGIS. Based on these data, we have classified chasma materials into geomorphological units according to their albedo, thickness, layering, elevation, and typical outcrop morphology such as flutes and polygons. We produced a geological map and a cross-section of the chasma. Then we compared the map with the location of ferric oxides and sulfates mapped from OMEGA data.

**Stratigraphy and structure** (Figures 2 and 6): The Noachian plateau is cut by the chasma. This No-

achian basement crops out along chasma wallslopes, which are eroded in the form of spurs and gullies. The basement crops out locally in the canyon in the form of horsts. Non-fluted ILDs consist of subhorizontal and thinly layered deposits of alternatively high and intermediate albedo (Figure 5). We do not observe any flutes on their slopes, suggesting a higher cohesion than that of the stratigraphically overlying fluted ILDs.

Table 1: Datasets and use in this study.

Name (Mission)	Type	Spatial/Spectral resolution	Use
MOLA [10] (MGS)	Laser altimeter	463 m, vert. ~1m	DEM Topography
HRSC [11] (MEx)	Camera	12.5-200 m	Nadir panchromatic images Geomorphology
THEMIS [12, 13] (MO)	Spectrometer	18-100 m	Vis. and IR images Geomorphology
MOC [14] (MGS)	Camera	1.4-12 m	Vis. images Geomorphology
HiRISE [15] (MRO)	Camera	25-32 cm	Near IR images Geomorphology
OMEGA [16] (MEx)	Spectrometer	0.3-4.8 km 0.38-5.2 μm	Vis. and IR spectra Mineralogy

These fluted ILDs consist of intermediate to high albedo material that is locally fluted (Figure 3a). Flutes are typically observed on the steepest ILD slopes (15°-25°). The development of flutes parallel to lines of steepest topographic gradients indicates gravity-driven rather than aeolian erosion. The morphology of the flutes suggests weak granular material such as shale, marl, sand or unconsolidated tuff. Erosional landforms derived from abrasion, such as yardangs, are also observed on shallow slopes and plateaus.

The cap rock and soft filling units are thin deposits overlying the fluted ILDs, either on hill tops, hill slopes, or on valley floors. They lie (and they are stratified) parallel to the topographic surface (Figure 3b). This intermediate albedo material may have been deposited by wind and may be poorly indurated materials such as volcanic ash, tuff, or dust.

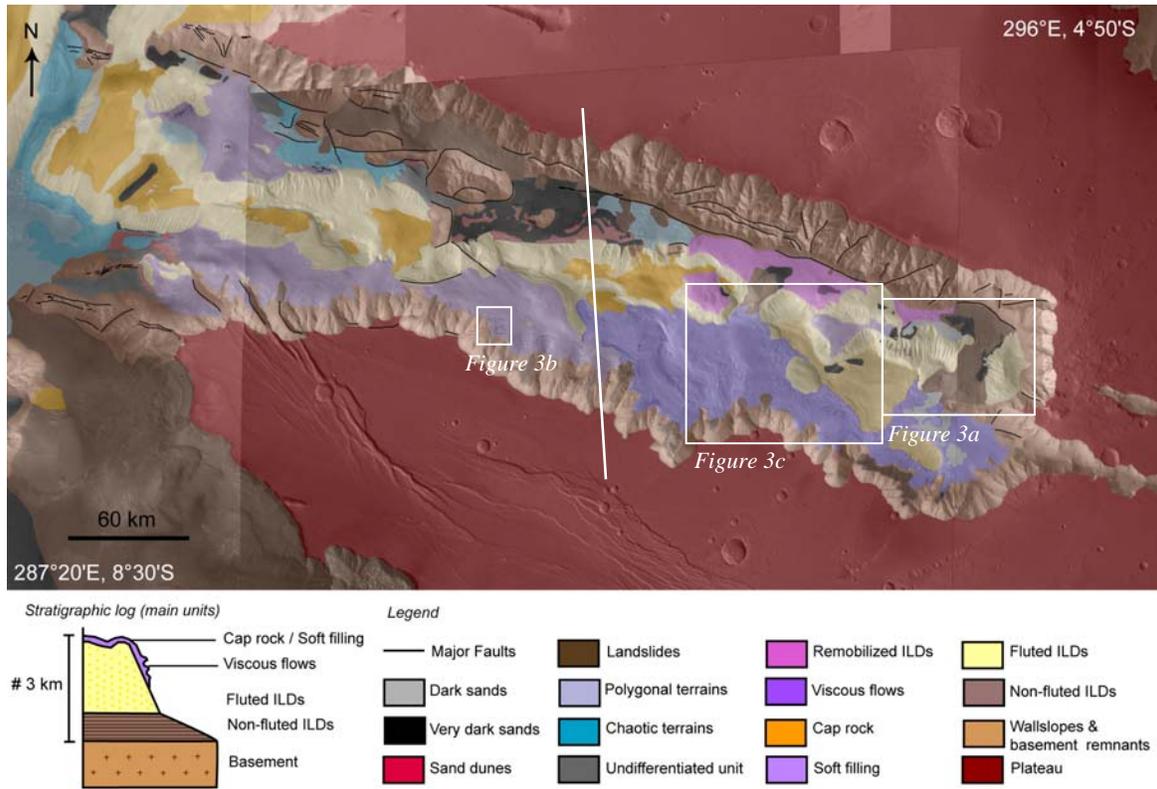


Figure 2: Preliminary geological map of East Candor Chasma on HRSC images. Locations of Figure 3a-c and the cross-section position of Figure 6 are indicated.

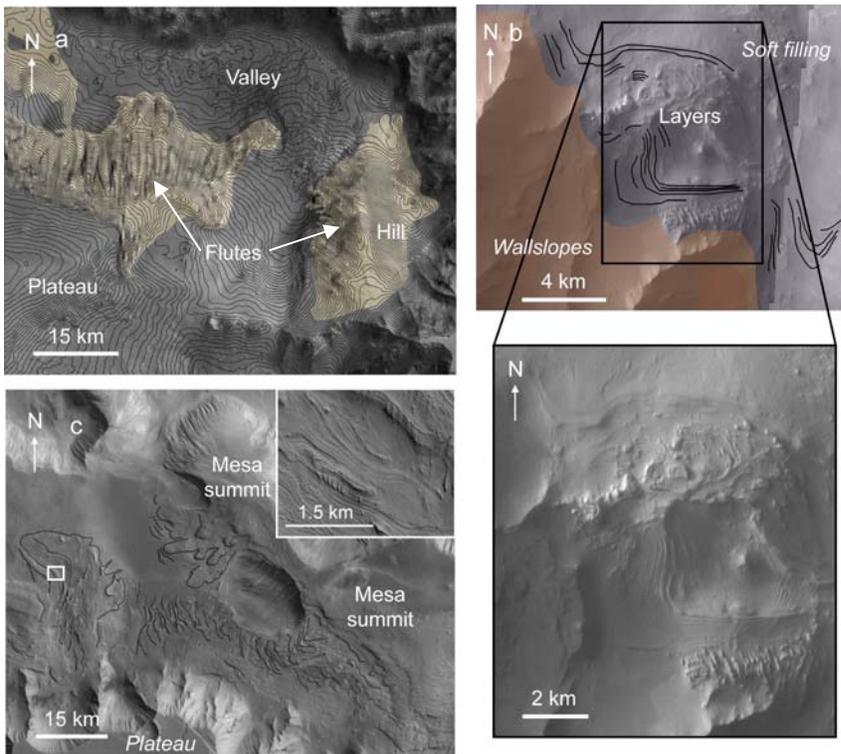


Figure 3: (a) Close-up view of fluted ILDs (in yellow) on a HRSC image. MOLA contour line with 100 interval. (b) Close-up view of the contact between the soft filling unit and the wallslopes. The bedding dips parallel to the walls. Portion of THEMIS Vis. image (V12635001). (c) Zoom on viscous flow unit. Portion of HRSC image (orbit 471). Ridges are in black. Zoom on a portion of MOC image (e1202244).

The *viscous flows* unit is located in the southeastern upper part of the chasma. It is characterized by small crescentric and imbricated ridges (*Figure 3c*, black lines) suggesting viscous flow moving parallel to lines of steepest topographic gradients. They may correspond to gravity remobilization of the *cap rock / soft filling* units, maybe due to the incorporation or a state change of volatiles in the rock unit.

The *remobilized ILDs*, observed at the bottom of the *fluted ILDs*, correspond to the redeposition of eroded *non-fluted ILDs* and *fluted ILDs*.

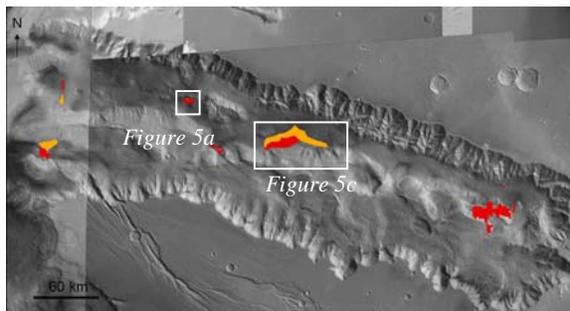
*Polygonal terrains* correspond to the fractured terrains as defined by [17]. *Chaotic terrains* (hummocky terrains in [17]) are located next to *polygonal terrains*. Both units are subhorizontal or slightly bulged. Their fractured or chaotic structure may result from interactions with volatiles such as ice or liquid water. Chaotic morphologies are a late evolution stage of polygonal landforms. Both units are observed to overlay, and hence postdate, the *fluted ILDs*.

Many *landslides* formed in the chasma. Wall rock landslides overlap, hence are younger than the *polygonal* and *chaotic terrains*.

The chasma is also filled with sand sheets, dunes and ripples, which have intermediate to high albedo.

*Undifferentiated unit* corresponds to material that is difficult to classify. It corresponds possibly to the *soft filling* unit.

**Mineralogical analysis:** We have detected and mapped ferric oxides in the chasma (*Figure 4*). The methodology we used has been exposed elsewhere [8, 9]. Sulfates (kieserite and polyhydrated sulfates) have also been reported (*Figure 4*) [7].



*Figure 4: Distribution of ferric oxides ( in orange) in East Candor Chasma obtained with a detailed study of OMEGA spectra, superimposed on a mosaic of HRSC images. Sulfates are in red. Location of Figures 5a and 5c is indicated.*

Ferric oxides and sulfates are often closely associated and occur in several patches throughout the chasma. MOLA altimetry indicates that the oxides are preferentially located in topographic lows.

THEMIS, HRSC and MOC images show that the ferric oxides are systematically correlated with superficial deposits of low albedo, in the form of sand sheets, dunes and ripples (*Figure 5*). They are located at the foot of, or partly mantle the ILDs (*non-fluted ILDs*, *fluted ILDs* and *soft filling* units). Sulfates correspond to outcrops of *non-fluted ILDs* and *fluted ILDs* (*Figure 5*). They formed either within the *fluted ILDs*, the erosion of which would have resulted in sulfate accumulations below over *non-fluted ILDs*, or within both units.

The spatial distribution of ferric oxides in regard with ILDs suggests that they are genetically linked. We suggest a formation scenario of ferric oxides and sulfates similar to Meridiani Planum [18,19]. During and/or after the formation of layered deposits (*non-fluted ILDs* followed by *fluted ILDs*), water in the form of groundwater recharge for instance resulted in the precipitation of sulfates. The precipitation of ferric oxides may have resulted from dissolution of mafic grains or Fe-rich sulfates by interaction with acid and/or oxidizing water enriched in ferric iron. Thereafter, aeolian erosion of the ILDs produced accumulations of ferric-rich deposits in topographic lows.

**Conclusion: geological history:** The following events in East Candor Chasma are proposed (*Figure 6*):

1. The chasma opened by tectonic extension, wall erosion carved the spur and gully morphology.
2. At the same time or later, *non-fluted ILDs* formed. The precipitation of sulfates and/or ferric oxides possibly occurred and require an aqueous environment.
3. Powdery material, either of lacustrine or volcanic origin (such as unwelded tuff) formed the *fluted ILDs*. Sulfates and possibly ferric oxides precipitated within the layers.
4. Intense erosion followed the setting of *fluted ILDs*, leading to a topography quite similar to the actual topography. Flutes were carved out in the material. Yardangs formed by wind action.
5. The *cap rock / soft filling* units are then deposited by aeolian processes. Volatile interactions result in the formation of *viscous flows* and *polygonal* and *chaotic terrains*, following an undetermined chronology. Aeolian erosion of the deposits results in accumulation of ferric material in dunes.

**Perspectives:** More detailed evolution, layer thickness variations, the correlation between tectonic development, erosion/deposition cycles, and climatic implications, will be obtained through quantitative analysis of topography, detailed cross sections, and comparison with other Valles Marineris chasmata.

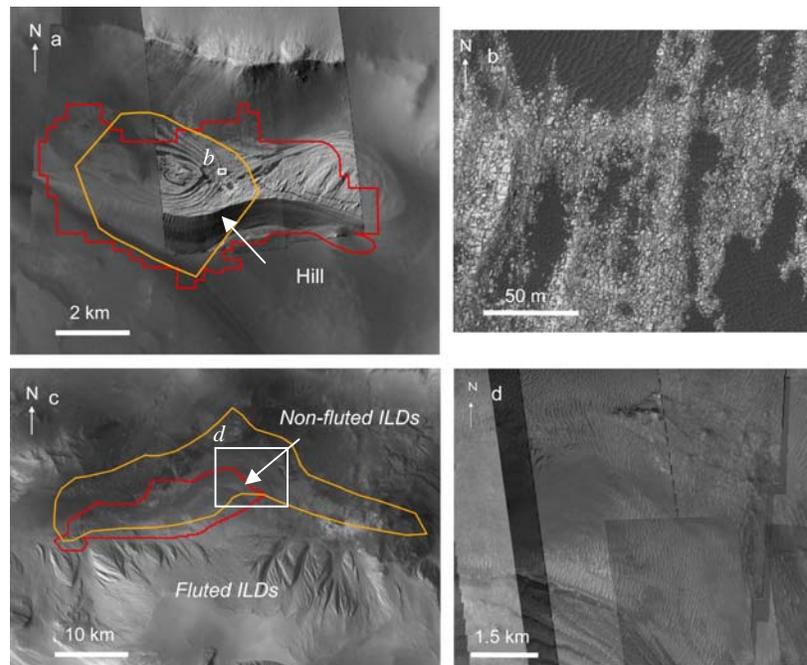


Figure 5: Examples of sites where ferric oxides (in orange) and sulfates (in red) are detected. (a) Hill made of non-fluted ILDs at center of basement remnants. Mosaic of THEMIS Vis. images & HiRISE image (PSP\_001390\_1735). (b) Close-up view of the HiRISE image (location on (a)). Ferric oxides correspond to dark sand dunes. Sulfates correspond to the light-toned material (non-fluted ILDs) that crops out between the iron -rich dunes. (c) Both minerals are partly located over fan-shaped non-fluted deposits. A possible feeding channel would be filled with fluted ILDs. (d) Close-up view of a portion of (c) (MOC mosaic) showing dark sand sheets and dunes enriched in ferric oxides. Sulfates may correspond to the light non-fluted deposits outcropping between the dunes.

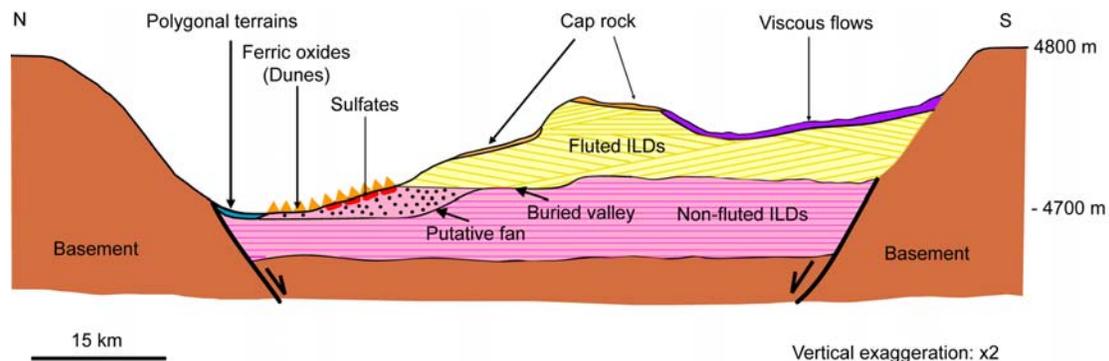


Figure 6: Cross-section of East Candor Chasma (location on Figure 2).

**References:** [1] Peulvast J.- P. et al. (2001) *Geomorph.*, 37, 329-352. [2] Lucchitta B. K. (1990) *Icarus*, 86, 476-509. [3] Chapman M. G. and Tanaka K. L. (2001) *JGR* 106(E5), 10,087-10,100. [4] Komatsu G. (2004) *PSS*, 52, 167-187. [5] Nedell S. S. et al. (1987) *Icarus*, 70, 409-441. [6] McCauley J. F. et al. (1972) *Icarus*, 17, 289-327. [7] Gendrin A. et al. (2005) *Science*, 307, 1584-1586. [8] Le Deit L. (2006) *LPSXXXVII*, Abstract #2115. [9] Le Deit et al. (2007) *LPSXXXVIII*, Abstract #1845. [10] Smith D.E. et al. (2001) *JGR*, 106, 23,689-23,722. [11] Neukum G. and R. Jaumann R. (2004) *ESA SP-1240*. [12] Christensen P. et al. (2004) *Science*, 306, 1733-1739. [13] Mellon M.T. et al. (2000) *Icarus*, 148, 437-455. [14] Malin M.C. et al. (1992) *JGR*, 97, E5, 7699-7718. [15] McEwen A.S. et al. (2007) *JGR*, in press. [16] Bibring J.-P. et al. (2004) *ESA-SP 1240*. [17] Lucchitta, B. K. (1999) MTM-05072, USGS Map I-2568. [18] McLennan S.M. et al. (2005) *EPSL*, 240, 95-121. [19] Squyres S. W. and Knoll A. H. (2005) *EPSL*, 240, 1-10.