A Volcano-tectonic activity:

Possible scenario beyond the formation of the rift systems in Noctis Labyrinthus (Mars)

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ABSTRACT

Noctis Labyrintus consists of a large network of rift systems and scalloped troughs, whose formation remains debated until nowadays. In the following study, we are analyzing the spatial correlation between faults, grabens and pit-chains to retrieve the sequence of events responsible for the formation of such a complex area, using Digital Elevation Model from HiRISE and MOLA and image mosaic from CTX. A major aspect of this study explores how extensional tectonic and volcanic plumbing together could be fundamental processes for the creation of such complex features in Noctis Labyrinths.

INTRODUCTION

Noctis Labyrinthus (NL) is located in the western part of the large extensional province of Valles Mariners and close to the vast volcanic plateau of Tharsis Montes [Fig.1]. It belongs to Phoenicis Lacus (MC-17) quadrangle and is defined by the coordinates: -6°86N_ 6°54S_267°48E_101°12W. The topography in this area shows a widespread distribution of major grabens, connected to different sizes of faults and surrounding scalloped pit-chains. The age of faults in Noctis Labyrinthus with respect to Valles Mariner is still indistinct, likewise, the different tectonic stages (Bistacchi et al., 2004; Schultz., 1998; Lucchitta et al., 1992 Schultz., 1991).

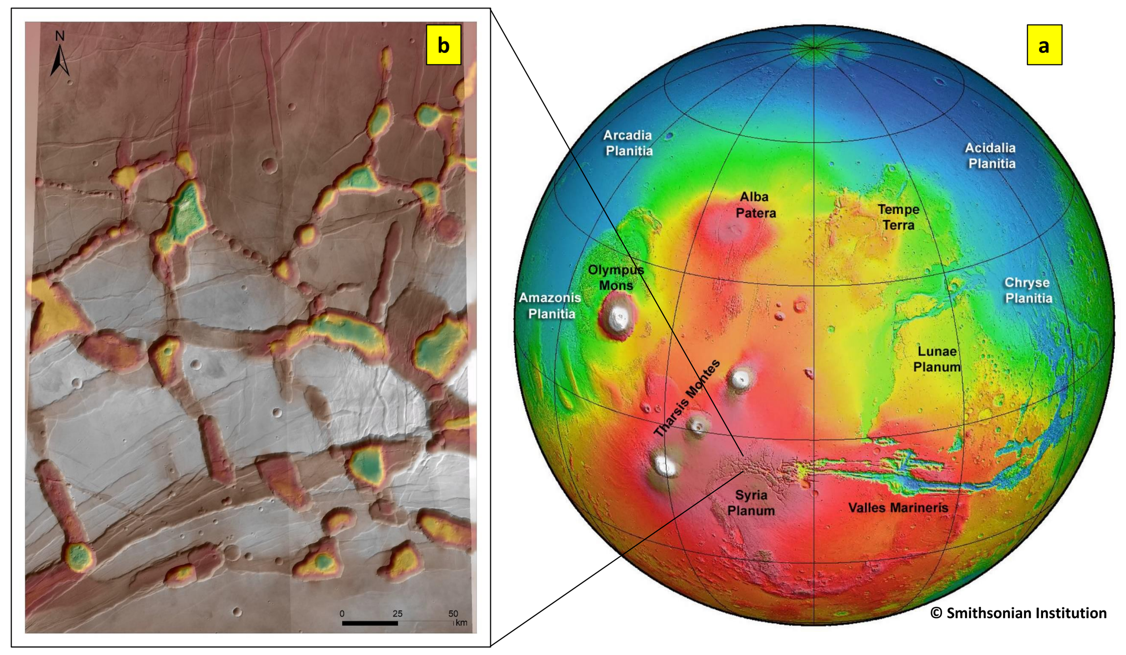

Fig.1. (a) Location of Noctis Labyrinthus in close vicinity to major geologic and topographic features on Mars.(b) Larger view of Noctis Labyrinthus over HRSC and MOLA basemaps.

Pit-chains and grabens follow predominatingly the same direction jointly, generating a complex grid of interconnected canyons and troughs (Greeley.,1994). Previous work interpreted NL as a karst landscape with associated caves and water-related processes (Baioni et al.,2017; Weitz et al., 2016; Jackson et al.,2011; Thollot et al.,2010; Grindrod et Balme.,2010; Bérezi., 2008; Murchie et al.,2007; Johnston et al.,2006; Bibring et al.,2006; Boston.,2004;), more else, a network of lava tubes (leone, 2014) or the result of volcano-tectonic activity (Mège et al, 2003, Schultz, 1998).

In this work, we performed a detailed analysis of faults and grabens systems to understand their mechanical evolution over different lengths and chronologies. We studied the faults geometrical properties, and we interpreted the surface geomorphology to display the general tectonic context of the area, scrutinize the pit-chains morphology and development, revealing the different processes behind the formation of NL.

MATERIALS AND METHODS

As a basemaps, we used the orthoimages H3210_0000 and H3221_0000 acquired by the High-Resolution Stereo Camera (HRSC) onboard Mars Express, bearing a resolution of 12.5 m/pixel, and a mosaic of images from context Camera (CTX), onboard Mars Reconnaissance Orbiter with 5.2m/px of spatial resolution. For the surface topography, we utilized an individual Digital Elevation Model (DEM) from Mars Orbiter Laser Altimeter (MOLA) onboard Mars Global Surveyor, with a resolution of ~460 m/pixel. We have mapped all apparent faults and grabens within the selected area (N=3781). Each fault was traced by a single polyline or by a group of polylines when segmented, and we distinguished their size by assigning different colors, while the pit-chains were delimited by a polygon shapefile [Fig.2.a].

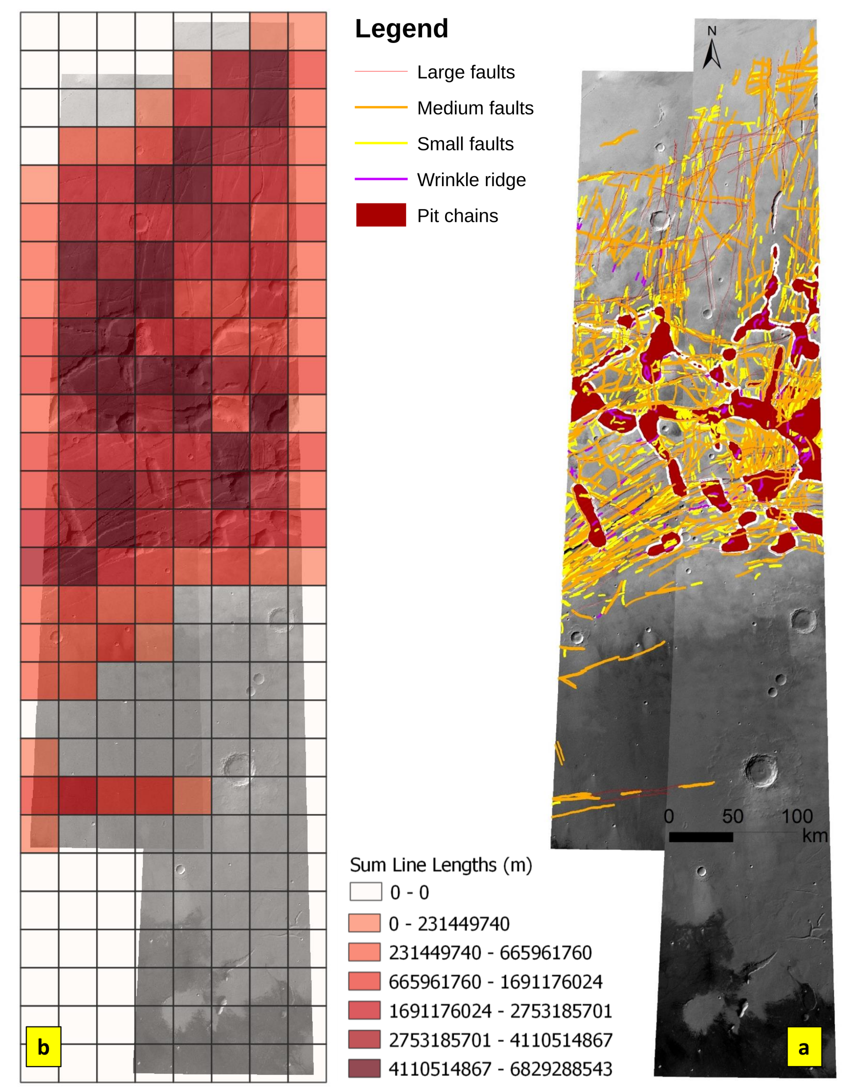

Fig.2. (a) Structural map of Noctis Labyrintus region. Image centered at 255.68° E, -5.945° N, over HRSC Basemap. (b) Intensity map for the sum line lengths measurements in meters for all mapped faults, over a grid of 30 X 30 Km Sq.

RESULTS

According to the occurrence of faults and pit-chains, a clear difference can be distinguished between the northern and the southern sectors of the working area [Fig.2.a]. The northern zone is basically consists of smooth terrains, lacking troughs and pit-chains, while in the southern zone, pit-chains are well developed and mostly parallel to the ENE-WSW fault system. The azimuth distribution of fault populations shows two main trends in the rose diagrams: ENE-WSW and NS [Fig.3]. The NS faults systems are apparently crosscut by the ENE-WSW faults system, which seems to occur before pit-chains formation. We assume that they are three different phases of faults, a primary NS faults group clearly observed in the north zone, followed up by the second phase of ENE-WSW that was probably generated after the pit-chains formation, and the last group of non-intensive NS faults that might also be the reactivation of the incipient NS fault group. Moreover, The intensity map for the sum line lengths of faults [Fig.2.b] shows a higher intensity in areas where pit-chains-Grabens features are expressed.

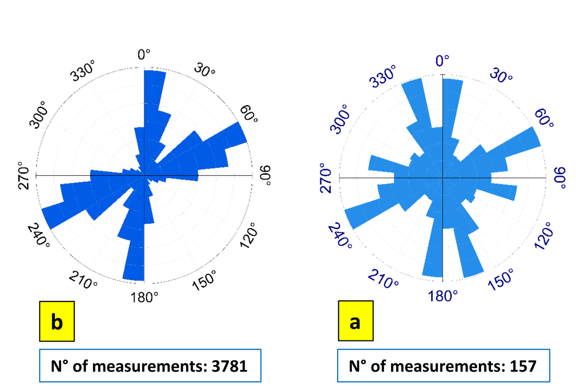

Fig.3. Rose diagrams for the pit-chains (a) and faults population (b).

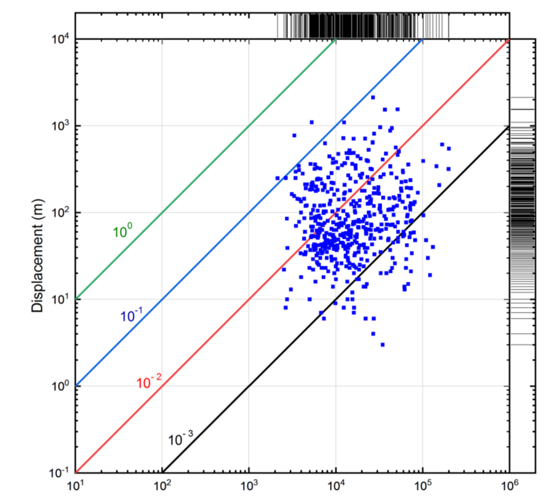

Fig.4. Displacement-Length diagram for all mapped faults, shows a large scattering of values (Left image)

Therefore, the length of the polylines determines the length of the faults, the maximum displacement of faults was measured through topographic shallow cross-sections, across all lineaments. Using these geometric parameters, we were able to set up a Displacement/Length diagram [Fig.4], expressed by the function: $D_{max}=\gamma . L^n$ (Cowie et al., 1992a,b; Dawers et al., 1993; Scholz et al 1993., Clark et al., 1992; Schlische et al., 1996; Schultz et al., 2008). The diagram displays a large scattering of values, γ varies typically over a range of 10^{-3} and 10^{-1}, which refers to normal faults (Seog Kim et all., 2005).

An additional observation shows a series of crosscutting faults [Fig.5.a], usually concentrated in the higher strains district, where we could assume the order of their superimposition. The interference between the different faults generates the formation of T, L, and X-Shaped intersections (Collanega et al., 2020), where faults are extended along two perpendicular directions produced by a Synchronous or 2-Phase bidirectional regional extension [Fig.5.b]. In the case where faults intersect at a 90° angle by a Synchronous radial extension, then the T and L-shaped intersections will be the common features, otherwise, for the 2-Phase bidirectional regional extension, one of the extensional phases should be NS and the other EW, to allow having T, L, and X Shaped intersections.

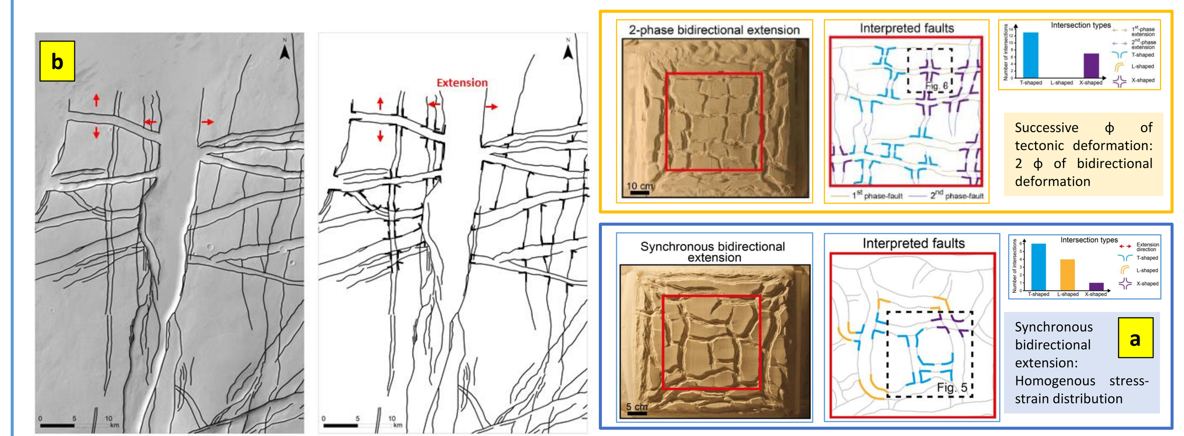

Fig.5. (a) Possible bidirectional extension scenarios for the formation of T, X and L shaped intersections (Right images. ©Collanega et al., 2020, modified). (b) Structural map on Noctis Labyrintus (Northest zone), showing some crosscutting intersection between faults. Image centered at 255.68° E, -5.945° N, over HRSC Basemap.

Moreover, a transtensional Pull-apart basin is generated by ENE-WSW left lateral strike-slip faults in releasing band (Fig.6.a), is considered as an evidence for transtensional deformation in this area. The Fig.6.b shows a segmented faults display and relay ramp, where faults are linked across the echelon steps. The northern sector of the working area shows a complex and intersected fault pattern, where the Riedel shear zone is slightly present and distributed over conjugate systems (Fig.7). The small-scale Riedel shear zone is commonly connected with a large-scale Riedel shear zone system, generates an extended grid of faults.

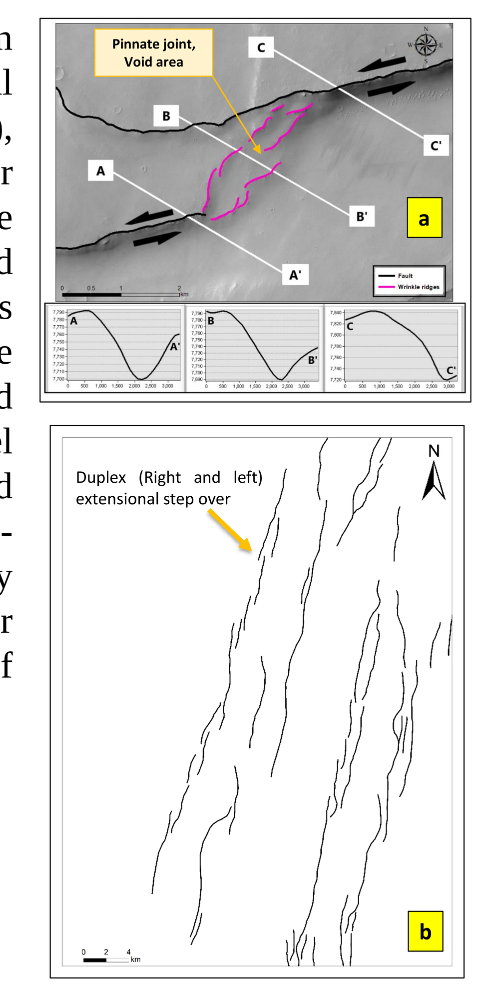

Fig.6. (a) Pull-apart basin generated by two strike-slip faults. The elevation profiles AA', BB', and CC' represent the topographic transition between faults highland and the basin. (b) Segmented faults and Incipient linkage across echelon step.

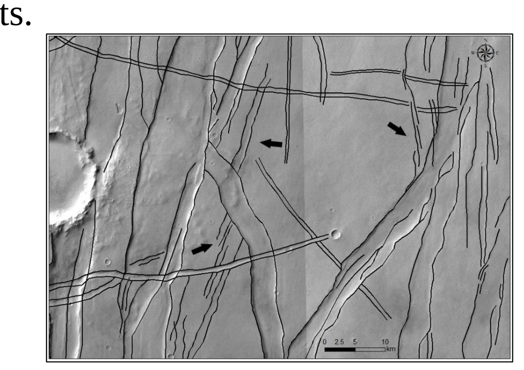

Fig.7. Plan view showing Riedel shear patterns, indicated by the black arrow, along with large-scale faults in a complex faulted zone. Image centered at 255.86°E, -3.40°N over HRSC basemap.

The surface geomorphology shows intricately connected systems of linear troughs, generated by rounded pit-chains and grabens. Pit-chains coalesce always in areas of extensional tectonics and are formed typically along the graben's footwall. These features are always connected to swarms of small size cracks, following mainly the same trend.

DISCUSSION AND CONCLUSION

According to the results we went through during this work, we infer a development of two fault systems potentially produced in response to bidirectional extension (Synchronous or 2-Phase of extension). Faults grow formingT, L, and X-Shaped intersections between faults. This shaped intersections play an important role in the formation of the branched complex grid of canyons and rift systems in Noctis Labyrinthus.

The presence of pit-chains remains difficult to explain within this setting. The striking spatial correlation between faults and pit-chains and the frequent interconnection between these features suggest a possible common mechanism for their formation. The interaction with magmatic activity from the large nearby Syria Planum magmatic complex might have played a role in shaping these structures. The scalloped troughs generated by the pit-chains and grabens could be classified as morphological features of volcanic collapse above dikes (Cattermole., 1992; Davis et al., 1995, Mège and Masson., 1996; Liu and wilson., 1998; Scott et al., 2000; McGetchin and Ullrich., 1973; Mège and Masson., 1996; Wilson and Head., 200; Ernst et al., 200; Mège et al.,2003; Zuber., 2001). Dikes fundamentally injected from the magmatic source that continuously generating flow, intruded below the graben floors might have exploited the local extensional setting, creating dilatant conditions in correspondence of major structures. Dikes play an important role in transporting the magma flow to the upper levels and a subsequent pressure drop in the plumbing system might have led to a surface collapse forming the large pit-chains afterward.

Thus we are suggesting a bidirectional extension in conjunction with the activity of a magmatic plumbing system as the main mechanisms for the formation of Noctis Labyrinthus features.

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