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Analysis of a Thaumasia Planum rift through automatic mapping and strain characterization of normal faults

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ABSTRACT

A new semi-automatic technique is presented to map and characterize tectonic features on Mars. Automatic strain estimation associated with normal faults is achieved for synthetic and real fault scarps on Mars.

The application of this new technique to a small rift located in Thaumasia Planum allowed the segmentation of the rift. The defined segmentation corresponds to changes in the strikes of faults that delimitate rift areas with different architecture.

The rift is formed by several pull-apart basins developed due to the reactivation of previously formed tectonic structures. The strain spatial distribution and the overall geometry are consistent with a roughly East–West left-lateral shear transfer zone between two different lithospheric blocks.

1. Introduction

Imagery datasets constitute the basis for tectonic studies on Mars. Tectonic lineaments are usually mapped and classified manually according to their structural significance (Anderson et al., 2001; Bistacchia et al., 2004; Borraccini et al., 2007; Fernández and Anguita, 2007). Several factors can influence the results of this tectonic analysis. Physical factors such as data spatial resolution, illumination conditions or the use of imagery from different sensors can potentially lead to different photo-interpretations.

The arduous and tedious work of lineament mapping is also dependent on the experience and personal style of the interpreter. A good example of the importance of those factors can be seen when comparing Hauber and Kronberg (2001) Tempe Fossae Rift structural map with the more recent map by Fernández and Anguita (2007). Both interpretations were made using Viking imagery with similar spatial resolutions. In the first case, the authors had chosen to make a more schematic interpretation, mapping only the major structures which greatly improve the interpretability of their map. Fernández and Anguita (2007) performed a more exhaustive mapping of the fault scarps, which in some cases produced an excess of lineaments that hinder the visualization of the tectonic pattern. This example illustrates the concept of scale dependence. Despite similar spatial resolution of the data, a different scale of analysis is an important factor that can influence the interpretations.

More important than these differences in style are the very different interpretations derived from both maps of the Tempe Rift. Fernández and Anguita (2007) proposed an oblique rift model in opposition with the continental rift model related with the uprise of a small mantellic plume proposed by Hauber and Kronberg (2001).

On the Earth the task of lineament mapping is also considered as a subjective task (Wise, 1982) but several automatic approaches have been developed (Argialas and Mavrantza, 2004; Koike et al., 1998; Masoud and Koike, 2006; Oakey, 1994; Tripathi et al., 2000) and human and physical factors that can influence the final results have also been studied (Podwysocki et al., 1975; Smith and Wise, 2007).

Imagery is important for mapping tectonic features but topographic data have been widely used for the characterization of these structures. Topographic data allowed the estimation of strains (Borraccini et al., 2005; Colton et al., 2006; Mège and Masson, 1996) and modeling (Masoud and Koike, 2006; Watters, 2004) of the different tectonic structures.

Several automatic methodologies have been applied on Mars for studying several geomorphologic features using remote sensing data. Terrain classification (Bue and Stepinski, 2006), drainage networks mapping (Stepinski and Collier, 2004) and crater counting (Bandeira et al., 2007; Bue and Stepinski, 2007) are some of the automated tasks. An automatic method for lineament extraction from MOLA (Mars Orbiter Laser Altimeter) data has been previously outlined (Alves et al., 2008; Vaz et al.,

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2007, 2008). Since then several improvements have been implemented, such as classification and morphometric characterization of the identified lineaments, which conducted to a new automatic method of strain estimation for distensive structures that will be presented in this work.

The automatic lineament mapping algorithm will be described and strain estimation derived from the mapping results is presented. A detailed strain analysis of a Thaumasia Planum rift is performed.

1.1. Geological and tectonic background

The Thaumasia Planum region is formed by older ridged plain materials (unit HNr) of Noachian to Early Hesperian age (Dohm and Tanaka, 1999; Dohm et al., 2001). It is located in the eastern part of the Thaumasia Plateau, between Melas Dorsa and Coprates rise (Fig. 1).

The tectonic evolution of the Thaumasia Plateau has been widely debated. Schultz and Tanaka (1994) recognized the compressive nature of the South Tharsis region and Dohm and Tanaka (1999) held that the plateau resembles the structural style of Earth intra-continental plateaus with large-scale anticlines forming the marginal ancient highlands. A thick-skinned followed by a thin-skinned episodes were proposed by Anguita et al. (2001) in a scenario where the Thaumasia Plateau slides as part of an independent lithospheric block. The idea of a Noachian-Hesperian orogeny, with the outer highlands acting as thrusts was later introduced by Anguita et al. (2006). A differential movement between two Thaumasia subunits was proposed. A southern unit thrusting to the South (forming the Southern Highlands) and a Northern unit thrusting to the East along the Coprates rise.

Topographic loading is usually invoked as a mechanism to explain the Thaumasia block ESE sliding and Montgomery et al. (2009) suggested the existence of a continental-scale basal detachment related with salts or salt-rich deposits.

The area analyzed in this work corresponds to a small rift system, comprised between Melas Dorsa and Lassell crater (Fig. 1), an area characterized by ~EW grabens that cut pre-existent ~NS wrinkle ridges (Fig. 2). The oblique nature of this rift is particularly evident in the western part, where grabens present en-echelon geometries denoting a clear transtensive regime related with an EW sinistral shear zone (Borraccini et al., 2007).

The rift is sub-parallel to Valles Marineris and it has been proposed that during Early Hesperian those structures acted as left-lateral transfer zones accommodating differential movements of the Thaumasia Plateau (Borraccini et al., 2007; Webb and Head, 2002). More recently this tectonic array has been interpreted by Montgomery et al. (2009) as a boundary between the main Thaumasia block and another smaller "plate" named Thaumasia Minor. The sinistral transtensional regime was also recognized in the western part of the rift and a possible transpresional regime was proposed to exist in the eastern section of the rift.

2. Data

The use of altimetry data for mapping geomorphologic structures allows a morphometric characterization that imagery alone cannot provide and also has the advantage of avoiding possible biases related with illumination conditions. Two main sources of topographic data are available for Mars: digital terrain models (DTMs) derived from stereophotogrammetry and MOLA laser altimetry (Zuber et al., 1992).

Stereo DTMs are mainly obtained from imagery acquired by the High Resolution Stereo Camera (HRSC) (Neukum et al., 2004) and the two cameras aboard Mars Reconnaissance Orbiter: Context Camera (CTX) (Malin et al., 2007) and High Resolution Imaging Science Experiment (HiRISE) (McEwen et al., 2007). The resolution and quality of the stereo DTMs can change according to acquisition conditions and even with the stereo matching algorithms used (Heipke et al., 2007).

Despite the better spatial resolution of stereo-derived DTMs (Kim and Muller, 2009), MOLA data coverage is still more complete and consistent, making it ideal for regional mapping. Integration of both kinds of datasets through data fusion seems to be a promising technique (Lin et al., 2010).

2.1. MOLA data

The size of MOLA shots footprint is approximately 150 m and the distance between the shots is 300 m (Smith et al., 2001).

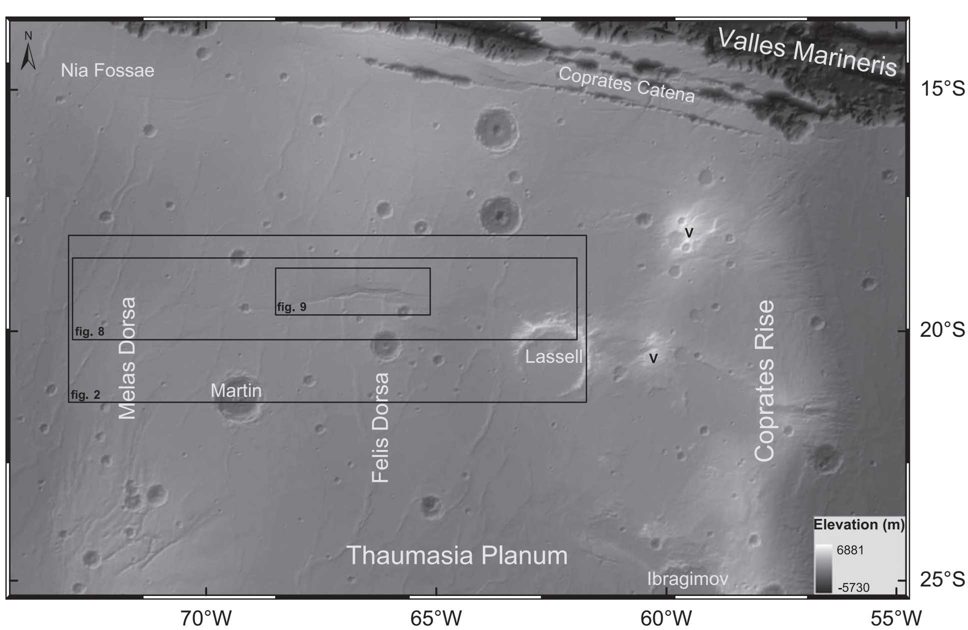

Fig. 1. Shaded relief topography of the studied area. Two degraded volcanic cones are marked with (V).