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Tectonic lineament mapping of the Thaumasia Plateau, Mars: Comparing results from photointerpretation and a semi-automatic approach

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ABSTRACT

Photointerpretation is the technique generally used to map and analyze the tectonic features existent on Mars surface. In this study we compare qualitatively and quantitatively two tectonic maps based on the interpretation of satellite imagery and a map derived semi-automatically. The comparison of the two photointerpreted datasets allowed us to infer some of the factors that can influence the process of lineament mapping on Mars.

Comparing the manually mapped datasets with the semi-automatically mapped features allowed us to evaluate the accuracy of the semi-automatic mapping procedure, as well as to identify the main limitations of the semi-automatic approach to mapping tectonic structures from MOLA altimetry.

Significant differences were found between the two photointerpretations. The qualitative and quantitative comparisons showed how mapping criteria, illumination conditions and scale of analysis can locally influence the interpretations. The semi-automatic mapping procedure proved to be mainly dependent on data quality; nevertheless the methodology, when applied to MOLA data, is able to produce meaningful results at a regional scale.

1. Introduction

Regional lineament mapping provides the basis for tectonic interpretation on Mars and represents one of the standard inputs for the creation of geological and geomorphologic maps. Image mosaics are usually employed, and lineaments are manually digitized and classified by the user (Geographical Information Systems—GIS, are nowadays used to manage the whole process).

Although the resolution and coverage of the available imagery already make it possible to carry out outcrop-scale structural analysis of Mars tectonic structures (Fueten et al., 2010; Schultz et al., 2010), regional studies continue to be performed in order to better understand the overall lithospheric structure and geodynamics of the planet (Anguita et al., 2006; Bistacchia et al., 2004; Fernández and Anguita, 2007; Montgomery et al., 2009; Spagnuolo et al., 2008).

On our planet, the task of lineament mapping from remote sensing data is considered a subjective task, and was even compared to a form of "art" (Wise, 1982). Several methodologies have been proposed in order to overcome this subjectivity (Argialas and Mavrantza, 2004; Fitton and Cox, 1998; Koike et al., 1998; Masoud and Koike, 2006, 2011; Oakey, 1994; Tripathi et al., 2000) and some of the factors that can influence the interpretative work have been analyzed (Podwysocki et al., 1975; Smith and Wise, 2007).

On Mars, several factors can influence the interpretative results. Some of the factors are subjective (such as the user experience/motivation or style) but others are easily quantifiable, such as the type and spatial resolution of the used datasets. Mosaic artifacts and illumination conditions can also influence the interpretation (Tanaka et al., 2010).

This comparative study will focus in the analysis of the tectonic features mapped in the Thaumasia Planum region (Fig. 1), a region that presents a rich and varied record of tectonic activity spanning Noachian and Hesperian times (Borraccini et al., 2007; Dohm and Tanaka, 1999).

The present study compares three different approaches to mapping. The first two datasets were obtained by the traditional method of photointerpretation using different imagery sources. The objective of comparing these datasets is to constrain some of the factors that can influence lineament mapping and thus the tectonic interpretation at a regional scale. The third case corresponds to a dataset obtained semi-automatically (Vaz, 2011). The aim is to evaluate the uncertainties and possible bias associated with the semi-automatic recognition procedure.

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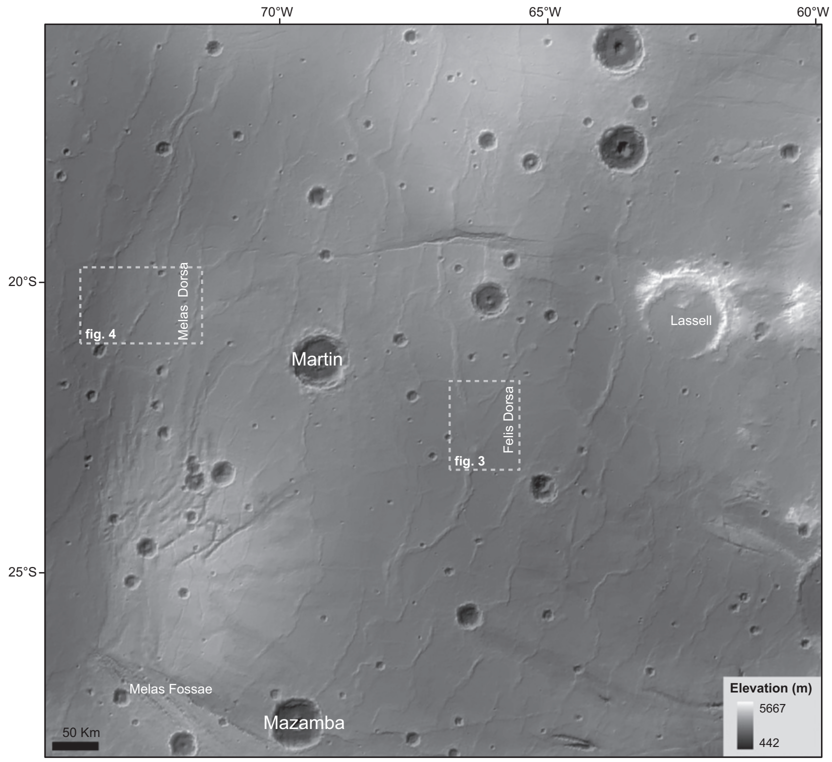

Fig. 1. Shaded relief topography of the studied area located in the Thaumasia Planum region. Dashed areas correspond to the regions shown in Figs. 3 and 4.

In the following sections, the three compared datasets are characterized and a qualitative and quantitative comparison is made.

2. Data and methodology

Dataset I corresponds to a section of the paleotectonic map of the Thaumasia region (Dohm and Tanaka, 1999; Dohm et al., 2001; PIGWAD, 2010). Dataset II corresponds to the detailed tectonic analysis of the eastern margin of the Thaumasia Plateau presented by Borraccini et al. (2007). Finally, dataset III present the tectonic features automatically extracted and classified in the manner described in Vaz (2011).

2.1. Dataset I

Dohm and Tanaka (1999) mapped tectonic lineaments using Viking images and a 1:2000,000-scale photomosaic base. The lineaments were then compiled on a GIS database at 125 m/pixel spatial resolution.

Several typologies of contractional tectonic features were originally distinguished (mare-type wrinkle ridge, narrow subdued ridge, etc.). Although these typologies characterize in more detail the different morphologies, for comparison purposes only two classes will be used, normal faults (NFs) and wrinkle ridges (WRs), including all the types of extensional and contractional structures, respectively.

2.2. Dataset II

The mapped structures in dataset II correspond to the more detailed structural mapping made by Borraccini et al. (2007). The authors used the Viking MDIM 2.1 mosaic (231.4 m/pixel), THEMIS infrared daytime mosaic (100 m/pixel) and a HRSC mosaic (50 m/pixel) to map tectonic lineaments on a GIS platform.

Borraccini et al. (2007) put emphasis on the recognition and characterization of the features from a structural rather than a morphological point of view. Three main categories, NFs, WRs and strike-slip faults were used to classify the mapped lineaments. In the present comparison only two classes will be used; NFs (including all the pure and oblique extensional features) and WRs (enclosing all the pure and oblique contractional structures). Pure strike-slip faults were distributed between the two classes depending on the context on which they appear.

2.3. Dataset III

Dataset III was generated semi-automatically. All the mapped lineaments were automatically derived from a MOLA (Mars Orbiter Laser Altimeter) digital terrain model (DTM). The MOLA laser pulses are spaced approximately 300 m along MGS (Mars Global Surveyor) ground tracks, and have a footprint diameter of $\sim$168 m (Neumann et al., 2001; Smith et al., 2001) with a vertical accuracy of <1 m (Neumann et al., 2001; Zuber et al., 1992). We have interpolated a DTM with $\sim$231 m/pixel from the MOLA precision experiment data records following the procedure described by Okubo et al. (2004) and applying the natural neighbor interpolation technique (Abramov and McEwen, 2004).

The algorithm presented in Vaz (2011) proved to be capable of automatic extraction of the topographic discontinuities present on Mars surface. Lineaments accurately mark the inflexion points of the scarps which allow the computation of several morphometric attributes for each scarp. The resultant dataset consists on a scarp database, where each line represents a topographic discontinuity on the DTM. The automatic procedure of scarp recognition is fully automated and reproducible. Then a user performs a classification stage on a GIS environment by superimposing the mapped lineaments on the available imagery. THEMIS daytime infrared (100 m/pixel), HRSC imagery (25 m/pixel) and CTX imagery (10 m/pixel) were the used datasets.