Automatic detection and classification of fault scarps on MOLA data. D. A. Vaz[1], M. T. Barata[1] and E. I. Alves[1], Centro de Geofísica da Universidade de Coimbra, Av. Dias da Silva, 3030 Coimbra, Portugal; e-mails: davidvaz@net.sapo.pt, tbrata@netcabo.pt and e.ivo.alves@netc.pt

Introduction: The mapping of lineaments from digital remote sensing data is one of the techniques used in the structural and tectonic characterization of a planet.

Lineament mapping on Mars is traditionally made using digital imagery [1,2]. MOLA altimetry data was also used to the visual interpretation and extraction of tectonic features from Mars surface [3]. All these works rely on traditional visual analysis and interpretation which is a time consuming and subjective task. We propose the use of an automatic and quantitative method, which allows the suppression of the subjectivity inherent to the process of traditional tectonic lineament mapping.

Methodology and results: The objective of this work is the automatic recognition of tectonic lineaments on Mars surface. In order to achieve this we use the MOLA Mission Experiment Gridded Data Records with a resolution of 128 pixels per degree. Although altimetry data are not as intuitive as visual imagery, they are not influenced by lightning or atmospheric conditions and do not suffer from camera or mosaic artefacts.

As showed by [4] wavelet edge analysis can be used to extract and enhance fault scarps in bathymetric data from seafloor. Following this idea our methodology starts with the application of a square filter of side 5. This filter is built using the first derivative of the cubic B-spline wavelet defined for 5 points.

The cubic B-spline function, $N_4(x)$ can be defined as:

$x < 0 \Rightarrow N_4(x) = 0$

$0 \le x < 1 \Rightarrow N_4(x) = x^3/6$

$1 \le x < 2 \Rightarrow N_4(x) = -(1/3) + x/2 + (x-1)^2/2 - (x-1)^3/2$

$2 \le x < 3 \Rightarrow N_4(x) = (2/3) - (x-2)^2 + (x-2)^3/2$

$3 \le x < 4 \Rightarrow N_4(x) = (5/3) - x/2 + (x-3)^2 - (x-3)^3/6$

$x \ge 4 \Rightarrow N_4(x) = 0$

The 1-D linear filter obtained is five times stacked in the N-S direction resulting in a 5×5 convolution matrix which is then tapered with a Hanning window in the E-W direction. Rotating 90º the N-S filter produces the E-W direction filter [4, 5].

As pointed by [4] the length of the 1-dimensional B-spline determines the width of the faults that will be identified and the number of identical linear filters stacked in the 2-dimensional matrix determines the fault length over which to average (smooth). In our case a 5×5 is used, but the use of larger filters allows the analysis at bigger scales.

Figures 1b and 1c shows the results of the convolution of the two wavelet filters applied to the Tractus Fossae region (figure 1a), a region that is crossed in the N10ºE direction by grabens that emanate radially from Tharsis [6]. As can be seen in figure 1b, the East and West dipping faults (positive and negative digital values) of the grabens are clearly discriminated. Figure 1c represents the same but for the North (positive digital values) and South (negative digital values) dipping directions.

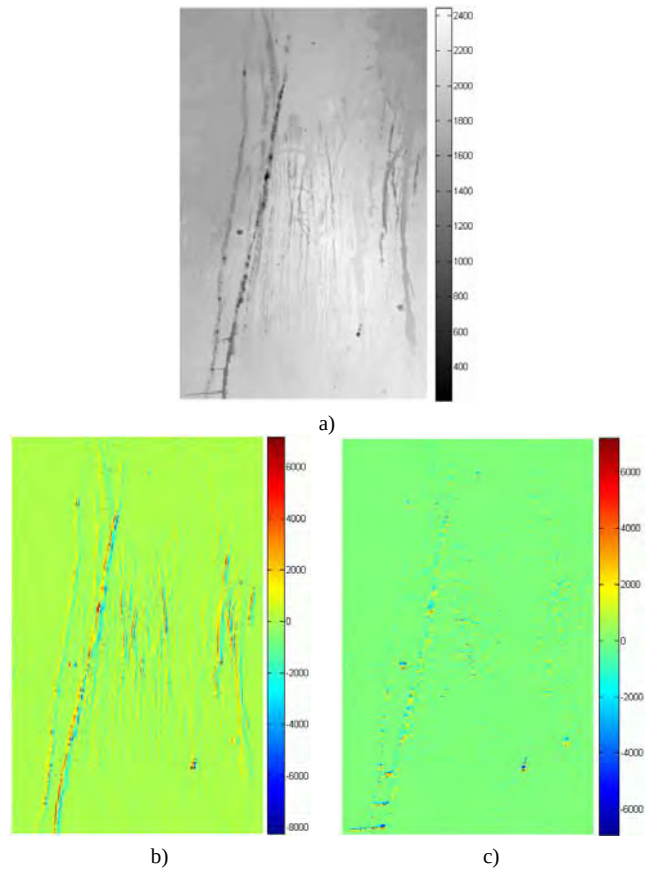

Figure 1 – a) MOLA original map, b) East and West (positive and negative digital values) dipping faults scarps, c) North (positive digital values) and South (negative digital values) dipping fault scarps.

The results appear promising although some noise is present; for instance, crater borders are also identified. In order to eliminate this and others noise features and also to reduce the scarp lines to one pixel width,

we have used morphological operators for binary images.

First a hysteresis threshold was performed and for each image two binary images are produced, each one representing each scarp dipping direction. Then each new image was submitted to the image processing procedures next described. By analysing the binary images we observe that there are some holes in the middle of scarp lines; to eliminate these we have performed a hole filling operation.

To reduce the fault scarp lines to one pixel width a thinning is then performed. This operation is applied twelve times to make objects narrower than twelve pixels end with one pixel widths. This will allow the elimination of wider objects (for instance volcanoes flanks that due to their high slopes are also identified by wavelet edge analysis). After the elimination of wider objects, scarp lines that are separated by one pixel are connected: this assures a good spatial continuity of the scarps.

The thinning operation produces lines which have many little branches. Those branches can be eliminated by performing a spuring, but the spuring also eliminates fault extremities which imply the reduction of fault length. This problem is easily handled by adding the reconstructed branches (using the endpoints of the fault lines as markers) to the pruned lines [7].

The final result of apllying the mathematical morphological operators are four binary images with one pixel width fault scarps, each image representing the direction of dipping of the scarps. Figure 2 shows an image obtained by merging those four binary images, each one coded with a different color.

It is now possible to perform several mesurements, for example fault strike determination, fault length, fracture density, etc. These measurements can be applied to all faults or only to faults dipping toward some desired direction.

Conclusions: The described methodology is fully automated and reproducible which allows a quantitative comparison and characterization of tectonic lineament patterns between different regions or even between different planets.

Further work must be done in the integration of the lineaments extracted by this method and other geomorphometric parameters that could be extracted from digital elevation models (slope and aspect of the scarps for instance).

The vertical displacement along faults should also be measured. The lineaments extracted could be used as markers in this process which will allow a better characterization of the grabens.

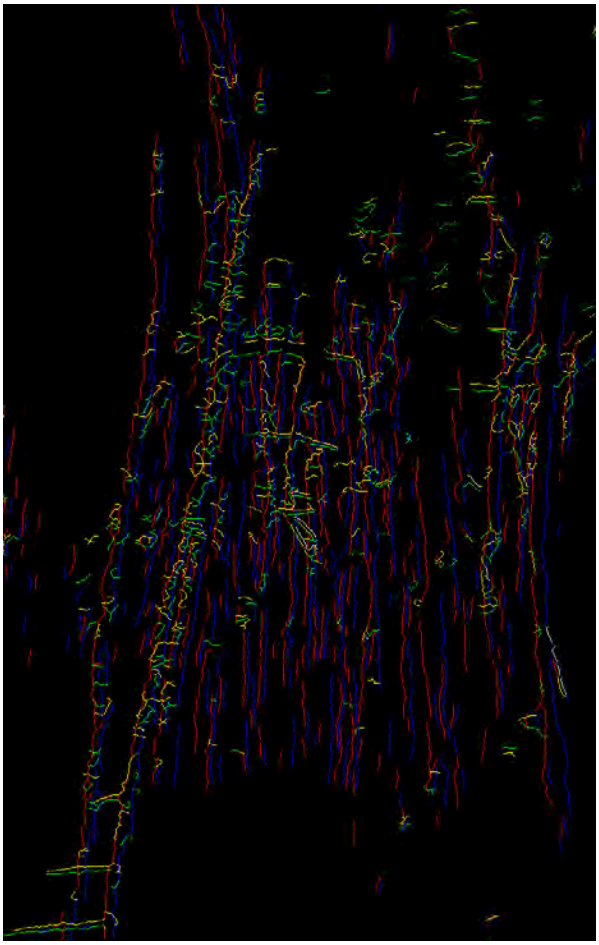

Figure 2 – Detected lineaments. Red - East dipping fault scarps; Blue - West; Yellow - South; Green - North.

References: [1] Dohm, J. M. et al. (2001) U.S. Geological Survey, I–2650, sheet 2. [2] Hauber, E. and Kronberg, P. (1999) *LPSC XXX*, Abstract #1568. [3] Deuchlera,C. et al. (2004) Inter. Arch. of Photogrammetry, Rem. Sens. Spatial Info Sciences, Vol. XXXV, B4. [4] Little, S. A. (1994) Wavelets in Geophysics, Academic Press, 167-182. [5] Vaz, D. (2005) Geoph. Res. Abs. , Vol. 7, 07092. [6] Cailleau, B. (2002) PhD Thesis, Mathematisch-Naturwissenschaftliche Fakultät, Kiel. [7] Soille, P. (1999) Morphological image analysis – principles and applications, Springer-Verlag.