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Inferring the subsurface geometry and emplacement conditions of a giant dike system in Elysium Fossae, Mars

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Abstract

Long and narrow grabens are a common superficial expression of dike emplacement at depth. We mapped 29 grabens belonging to a NW-SE trending extensional system located at the east flank of Elysium Mons based on detailed CTX images. An area-balance calculation along perpendicular topographic MOLA profiles was performed, in order to estimate true dike widths (D_w) associated to graben widths (G_w). The graben widths were transformed in estimated widths of the underlying dikes using the D_w/G_w relationship previously calculated. Then, possible stress factors for the host rock and magma overpressures were calculated. The aspect ratios, stress factors, and pressures obtained from the dike widths and graben lengths are consistent with those generated by fluid-filled fractures, suggesting that this method can be used to identify the grabens generated by dike intrusions.

1. Introduction

Dike emplacement at depth is used to explain some of the radial and concentric graben systems in the Martian volcanic provinces [e.g., 1, 2]. Evidence for dike intrusion as the generating mechanism includes the results of magma-ice interactions, i.e., massive water flows [2], or dike-induced topography [4]. We suggest that the surface geometry of grabens may be used as an additional tool to infer such mechanism.

The area of study is located in the eastern flank of Elysium Mons (Fig. 1), and consists of a set of NW-SE-trending linear grabens which extend over 360 km. We mapped 29 individual structures and measured their maximum continuous lengths (L, between 1.9-156 km) and maximum widths (W, between 0.13-3 km).

2. Area-balance calculations, from graben to dike geometries

We have used data from the MOLA PEDR, to construct 20 topographic profiles normal to the structure strikes, used in the area-balance calculations for each observed graben. Assuming fault dips of 60º, a sub-horizontal regional level, and defining the position of fault escarpments through CTX (30m/px res.) images, we have calculated the boundary displacement and lost area below regional for each graben. Assuming that extension in the graben was caused only by an intruding dike, we use the former as a proxy for average dike width. Area-balancing results show strong correlations between graben widths ($G_{w.}$), top-dike depths, graben depths and dike widths (D_w).

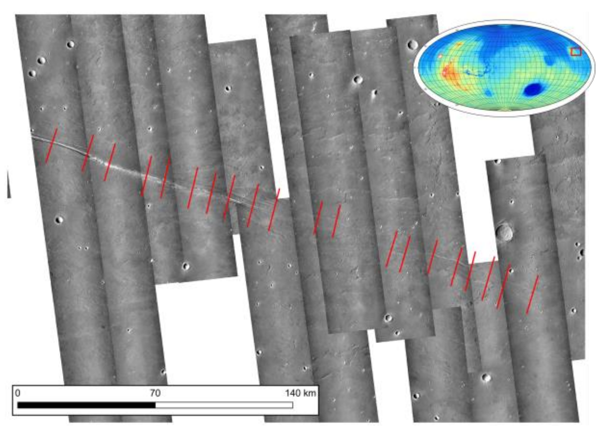

Figure 1. Global location and detail of the studied graben system. In red, the topographic profiles used for area-balance.

However, not all the 29 structures mapped in CTX can be identified by MOLA, either due to lack of coverage, or because their widths are below the instrument's resolution. Consequently, dike widths cannot be calculated directly for all structures through area-balance. Instead, we have used the G_w-

D_w relationships to extrapolate all the initial graben widths (W) to dike widths.

3. Emplacement conditions

The aspect ratio (*Width/Length*) and *Length* of a given set of fluid-filled fractures are related via a power-law function in which the n exponent is near -0.5 [4] (Fig. 2). The W/L vs L relationship in the grabens mapped initially was consistent with this theory, and when transforming W to D_w (the lengths are maintained and assumed the dike lengths), this relationship holds true (Fig. 2). The dike widths obtained are between 6-132 m.

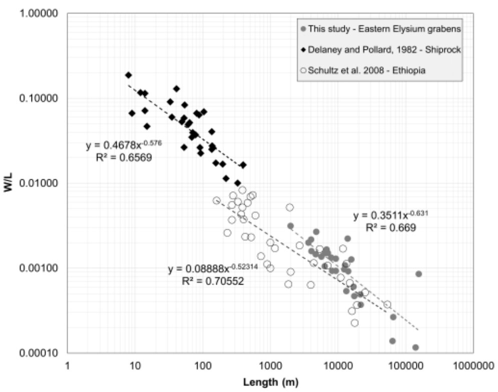

Figure 2. Width/Length vs Length (m) for the studied grabens (filled circles), a set of Ethiopian dikes (empty circles) [7], and the Shiprock dikes (filled diamonds, reference in [3]).

The *stress intensity factor* (K_{i}) of the host rock can be derived from the power functions [3], obtaining 3.4-16.9 GPa m$^{1/2}$ (assuming Young Modulus of 15-75 GPa, from altered to intact basalts, and Poisson Ratios of 0.2-0.3). These values are similar albeit slightly higher than those calculated from a set of basalt-hosted Ethiopian dikes [7]. Finally, the excess pressure ΔPe (the difference between the fluid pressure and the lithostatic stress) under which fracturing occurred can be derived from K_i and the fracture's half-length a ($a = L/2$) via [3]:

$$\Delta P_e = \frac{K_i}{\sqrt{\pi a}} \quad (1)$$

The excess pressure ΔP_e obtained range between 1-300 MPa, which are within the order of magnitude of modeled pressures for radial dikes in Tharsis [6].

4. Conclusions

The dike widths estimated for the studied grabens yield aspect ratios consistent with fluid-filled cracks (e.g., [3, 7]). Their widths are slightly higher than those of terrestrial structures with the same lengths. These differences are likely caused by the shorter Martian gravity [8]. K_i and ΔP_e obtained are consistent with those from other authors through independent methods, both on Earth and Mars. Therefore, the method proposed here may be used to identify if dike emplacement is the mechanism responsible for graben formation in other areas of Mars. It can also be used to make inferences about the properties of the brittle crust and driving magma pressures.

Acknowledgements

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