GEOMETRICAL ANALYSIS OF SHEAR-FRACTURE RIBBONS IN OVDA REGIO, VENUS. R.R. Ghent[1] and V.L. Hansen[2], [1,2] Department of Geological Sciences, Southern Methodist University, Dallas, TX 75275
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Introduction. Since NASA's Magellan mission to Venus, much controversy has surrounded the geodynamics and thermal and lithospheric evolution of the planet. Crustal plateaus are central to this controversy. Models for crustal plateau formation figure prominently in general geodynamic models, and surface structures are key to crustal plateau evolution. Ribbons [1,2] in particular are the fingerprints of crustal plateau deformation, so understanding the mechanics of ribbon formation may contribute to our overall understanding of crustal plateau evolution. Ribbons are extensional features and have two end-member varieties: tensile-fracture ribbons, which by form by tensile fracturing and subsequent extension of a thin brittle layer over a ductile substrate, and shear-fracture ribbons, which form by shear fracturing and subsequent extension of a slightly thicker brittle layer over a ductile substrate [2]. Tensile-fracture ribbons exhibit V-shaped terminations and lack accommodation structures; individual troughs can be traced for distances up to 170 km in some cases and have widths on the order of 1-3 km [2]. Shear-fracture ribbon troughs are also on the order of 1-3 km wide, but exhibit parallel trough wall terminations and accommodation structures, which appear in SAR images as multiple interior lineaments. Shear-fracture ribbon troughs have a tendency to branch, making individual shear-fracture ribbon troughs shorter than tensile-fracture troughs and more difficult to follow, though individual trough lengths range up to ~100 km. Shear-fracture ribbons dominate in Ovda Regio.

Hansen and Willis [2] analyze tensile-fracture ribbon geometry in detail, and use terrestrial boudins as mechanical analogs for ribbons to deduce competent layer thickness during ribbon formation and to calculate extension accommodated by ribbons. The present work attempts to perform a similar analysis for shear-fracture ribbons in Ovda Regio. We describe and quantify the strain accommodated by ribbons and evaluate the validity of boudinage as a mechanical analog for shear-fracture ribbon formation.

Observations. In SAR images shear-fracture ribbons are similar to tensile-fracture ribbons in terms of spacing, trough and ridge widths, and aspect ratios. Individual shear-fracture ribbon troughs, however, are delineated in SAR images by multiple lineaments, rather than single bright and dark lineaments, and therefore are more difficult to trace. Shear-fracture ribbons resemble shallow, narrow graben whose walls are likely steeply dipping normal faults. A single wall consists of one or more faults which step downward toward the trough floor. Because of this graben-like morphology, measurement of shear-fracture ribbon wavelengths is not as straightforward as measurement of tensile-fracture ribbon wavelengths. The wavelength needed for layer thickness calculation is the distance between incipient failure planes in the competent layer. In the case of tensile fractures, this wavelength is simply the ridge width, because trough walls were in contact prior to fracturing. We measure shear-fracture ribbon wavelength as the distance from trough center to trough center; this method for measuring wavelength yields a *maximum* wavelength because it includes the incipient wavelength plus the amount of finite extension. Therefore, estimates of layer thickness for shear-fracture ribbons calculated using wavelengths measured in this way are *maximum* estimates, and resulting estimates of extension are *minimum* estimates.

In order to measure shear-fracture ribbon wavelengths, we digitally measured trough and ridge widths directly from FMIDR images for several transects oriented perpendicular to ribbon trends in Ovda Regio. It is not practical to measure from trough center to trough center in SAR images; therefore, we measured from outer trough wall to outer trough wall for each transect, then calculated the wavelength of each trough-ridge-trough set. Wavelengths measured in this manner are between 1.6 and 2.1 km [4].

In order to better quantify shear-fracture ribbon wavelengths, work is under way to conduct a spectral analysis of FMIDR digital images. This analysis will produce a spectrum in the wavenumber domain in which dominant wavelengths will be apparent and will give an objective measure of these wavelengths.

Interpretations. Hansen and Willis [2] use boudins as mechanical analogs for ribbons. Boudins come in several different varieties, usually classified according to their shapes: for example, rectangular, rhomboidal, or barrel-shaped. Some boudins are the result of combined brittle and ductile deformation: a strong layer may experience some ductile flow, forming pinch-and-swell structures, then subsequently fracture along brittle tensile or shear fractures. Others experience only brittle fracture, either tensile or shear. For comparison with shear-fracture ribbons, boudins created by shear failure are the most relevant.

Shear-fracture boudins occur in a number of natural and experimental environments, both in single and multiple compositional layers, in foliated sequences, and in glacier ice [5,6,7,8,9]. A number of authors [10,11,12,13,14,15] examine tensile-fracture boudinage mathematically or using finite element modeling. Such treatments are less extensive for shear-fracture boudinage [5,6]. Because of the regular spacing of shear-fracture ribbons in Ovda Regio and the similar map patterns defined by shear-fracture ribbons and shear-fracture boudins, we believe that shear-fracture boudins are a viable analog for ribbons in Ovda Regio, and that wavelength:layer thickness ratios for shear-fracture boudins can be applied to Ovda's ribbons.

Terrestrial boudins commonly have wavelength:layer thickness ratios of 2-4 [7]. Using these ratios and Ovda's shear-fracture ribbon wavelengths of 1.6 - 2.1 km, we estimate competent layer thickness as 0.4 to 1.1 km during ribbon formation. That is, at the time of ribbon formation in Ovda Regio, the brittle-ductile transition was very near the surface over vast areas [4].

We estimate extension accommodated by shear-fracture ribbons using

$$e = \frac{d/D}{1 - d/D + \left(N_r w_{rm} / N_t w_{tm} \right)}$$

where d is ribbon trough depth, D is layer thickness, N_r and N_t are the number of ridges and troughs, respectively, across a transect and w_{rm} and w_{tm} are the mean ridge and trough widths, respectively. We cannot rigorously quantify d, the trough depth, in Ovda Regio, as there is minimal radar layover at the equatorial region, and because the scale of ribbon troughs is so close to the maximum resolution of SAR images. Therefore we calculate extension for various ratios of d/D. We do not account for any ductile flow of material prior to rupture, nor for any thinning of the competent layer beneath ribbon troughs, which likely occurs [16]. All of these factors mean that our estimates of surface extension are minimum estimates; we calculate shear-fracture ribbon extension in Ovda Regio as 10-50% [4].

Summary. We observe that in Ovda Regio, shear-fracture ribbons dominate over tensile-fracture ribbons, as in Fortuna Tessera. These shear-fracture ribbons are similar to tensile-fracture ribbons in terms of width, spacing, aspect ratio, and likely, depth, but differ from tensile-fracture ribbons in that their walls are composed of multiple steeply-dipping normal faults rather than single tensile fractures. We conclude that these shear-fracture ribbons can be compared to shear-fracture boudins and that shear-fracture boudin wavelength:layer thickness ratios can be used to calculate competent layer thickness during ribbon formation. The resulting layer thicknesses are then used to calculate minimum estimates of shear-fracture ribbon extension. Layer thickness calculations indicate that the brittle-ductile transition was very close to the surface during shear-fracture ribbon formation in Ovda Regio, as has been suggested for Fortuna Tessera [1,2]. This conclusion in turn may provide constraints on models of formation and evolution of Ovda Regio, as any such model must be able to explain how it is that the BDT was so close to the surface.

Similar analyses should be conducted for shear-fracture ribbons in other crustal plateaus, such as Thetis Regio, in order to see how competent layer thicknesses and estimates of extension compare with those for Ovda Regio.

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