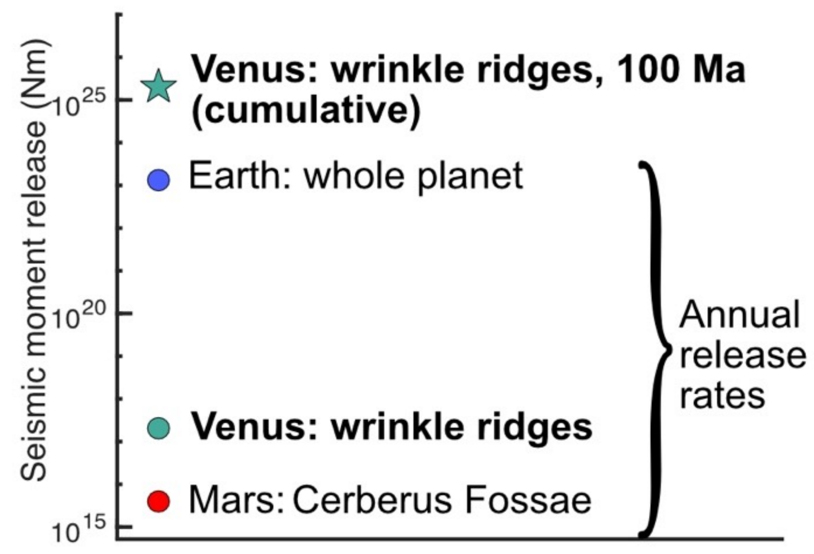
National Aeronautics and Space Administration

Predicting seismicity using fault scaling relationships: from Mars to Venus

Leah Sabbeth, JPL Postdoctoral Fellow (3226)
Suzanne E. Smrekar (3226), Joann M. Stock (Caltech)

Conclusions:

We have devised a **simple method to estimate planetary seismicity** by using Leonard's (2010) scalar relationship between fault lengths and moment release. **Segmentation** is important to produce a realistic magnitude-frequency distribution, and **plausible faulting depths** limit maximum fault dimensions. **Time of deformation** is important in any estimate seismicity rate.



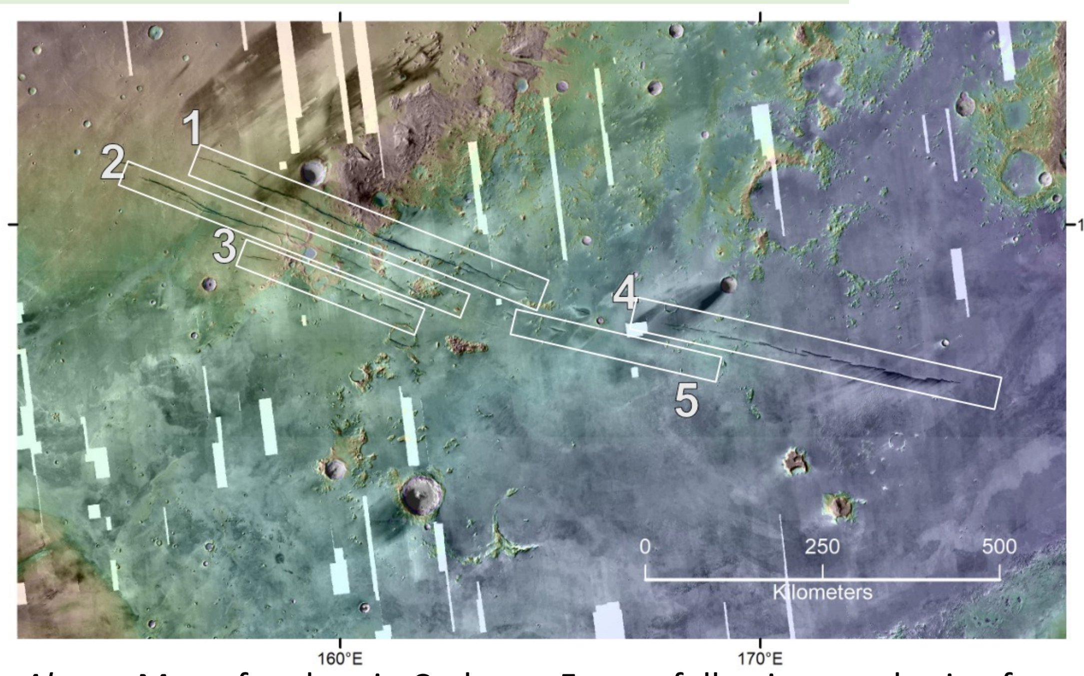
Left: Comparison of annual seismic moment release measured on Mars (red circle) (Stähler et al., 2022), Earth (blue circle), and cumulative (green star) and annual (green dot) estimates for Venus using a maximum throw of 30 km.

Questions:

How can we estimate seismicity on Venus?

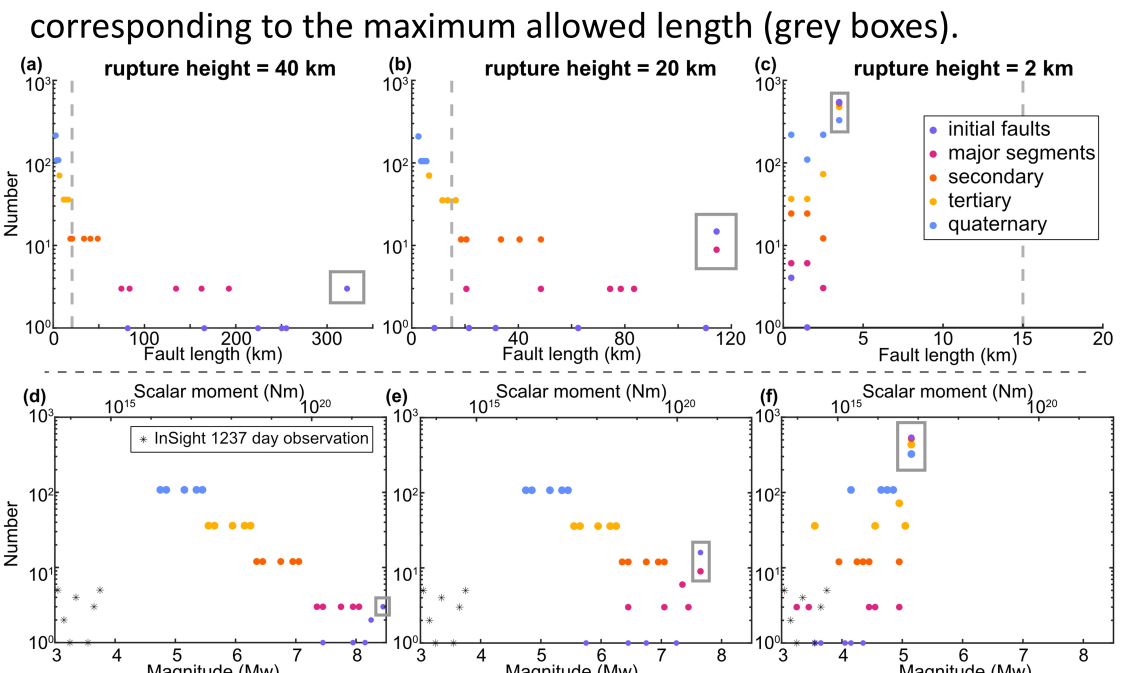
- Predictions of magnitude, frequency, and location are for future missions
- How does Venus compare to Earth and Mars?
- Previous methods are complex & require many geophysical constants.

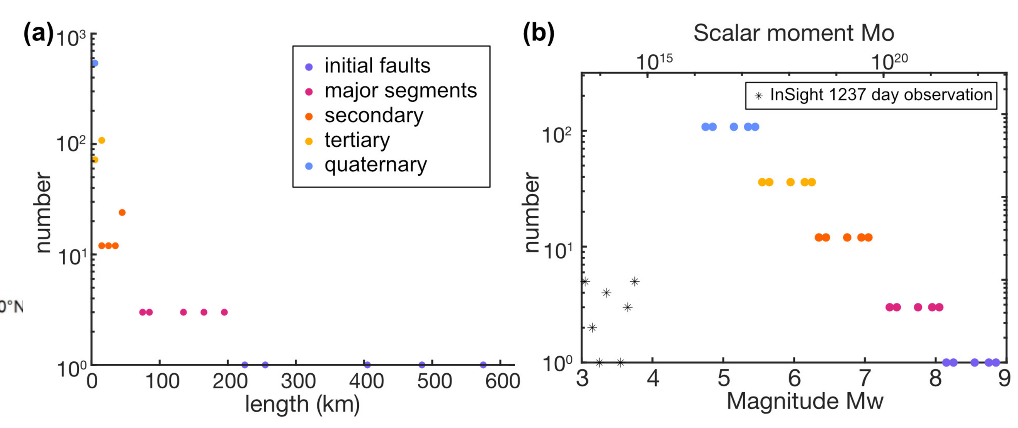
Cerberus Fossae graben on Mars:



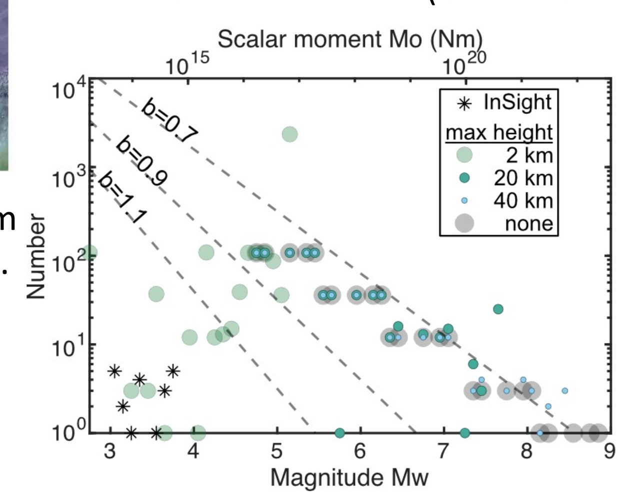
Above: Map of graben in Cerberus Fossae following numbering from (Taylor et al., 2013) and including graben 5 from Perrin et al. (2022).

Below: Histograms of segmented graben with lengths limited by throws of 40 km (a), 20 km (b), and 2 km (c) with a reference line of 15 km (grey dashed line). Calculated scalar moments are shown below respective lengths (d, e, f). Note that imposed maximum throws create a high population of events at a magnitude corresponding to the maximum allowed length (grey boxes).





Above: histograms of (a) whole and segmented fault lengths (b) calculated scalar moments and 22 detected seismic events from Cerberus Fossae (Clinton & Euchner, 2022).

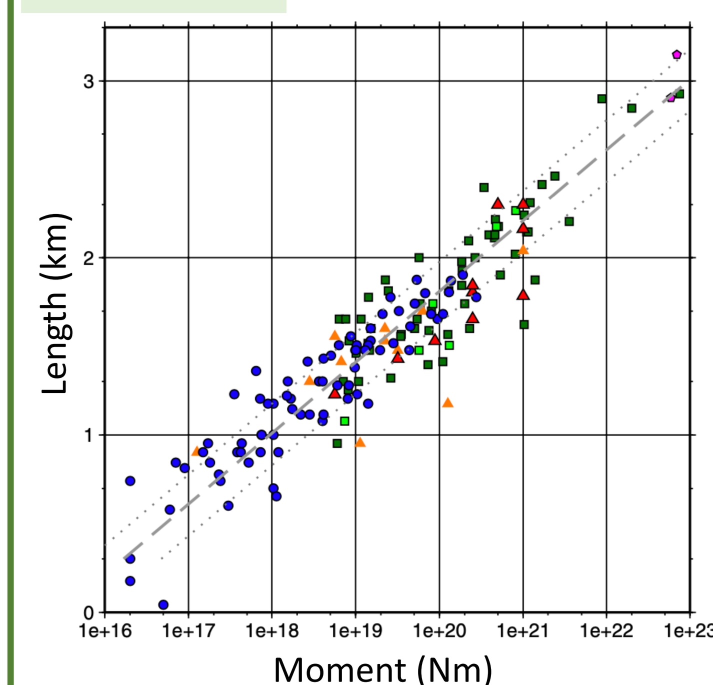


Left: Magnitude-frequency histogram for modeled marsquakes and relevant events recorded by InSight. Dashed lines represent b-values, with no particular y-intercept, of typical terrestrial regimes.

Below: Comparison of previous estimates for annual seismic moment release for Mars and Cerberus Fossae.

Study & details	Annual Moment Release (Nm)
This study: Cerberus fossae	
segmentation only	6.2×10^{15}
maximum faulting throw... 2 km	1.7×10^{13}
40 km	3.6×10^{15}
Taylor et al. (2013) Cerberus Fossae, fault throw	$1.14^{+1.04}_{-0.62} \times 10^{17}$
Stähler et al. (2022) Cerberus Fossae, InSight meas.	1.4 to 5.6×10^{15}
Golombek et al. (1992)	
global, surface faulting	1.3×10^{15}
global, lithospheric cooling	$\sim 10^{18}$
Knapmeyer et al. (2006) global, surface faults	3.42×10^{16} to 3.36×10^{20}
Plesa et al. (2018) global, thermal model	5.7×10^{16} to 3.9×10^{19}

Methods:

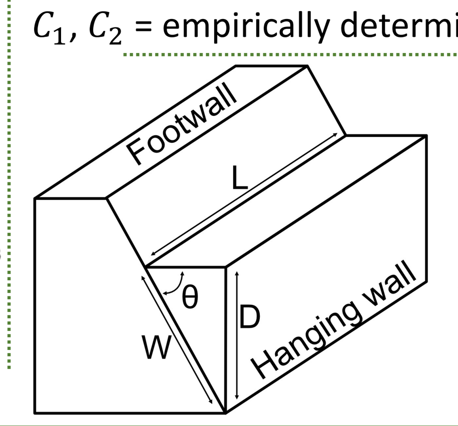


Above: terrestrial data for dip-slip interplate quakes (Leonard, 2010)

Earthquake fault scaling: self-consistent relating of rupture length, width, and moment release

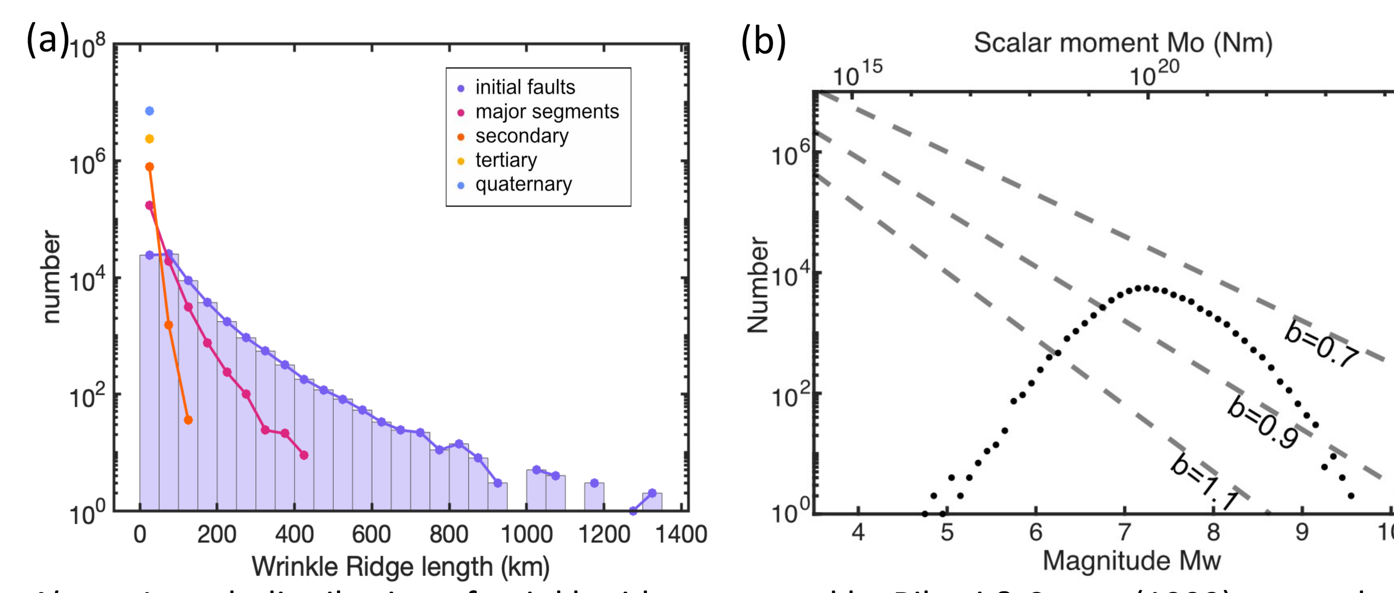
$$\log M_O = \frac{5}{2}\log L + \frac{3}{2}\log C_1 + \log C_2\mu$$

M_O = seismic moment (Nm) Leonard (2010)
L = fault length (km)
μ = shear modulus (24 GPa)
C_1, C_2 = empirically determined constants



Left: schematic of normal fault with length (L), width (W), and throw or depth (D).

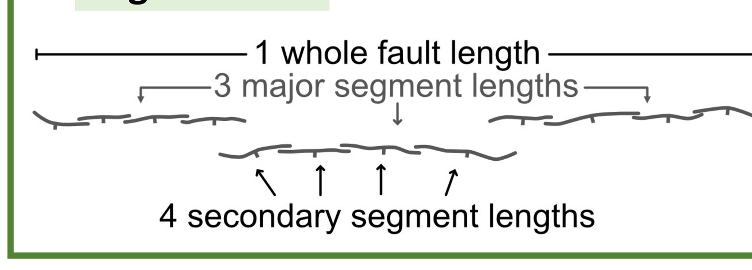
Lengths and calculated magnitudes from mapped wrinkle ridges:



Above: Length distribution of wrinkle ridges mapped by Bilotti & Suppe (1999) as purple bars, with lines showing lengths from segments (a). Scalar moments calculated from mapped wrinkle ridges (b), with typical distributions, or b-values, for terrestrial regimes.

Solutions for distribution and range of magnitudes:

1. Segmentation for better distribution



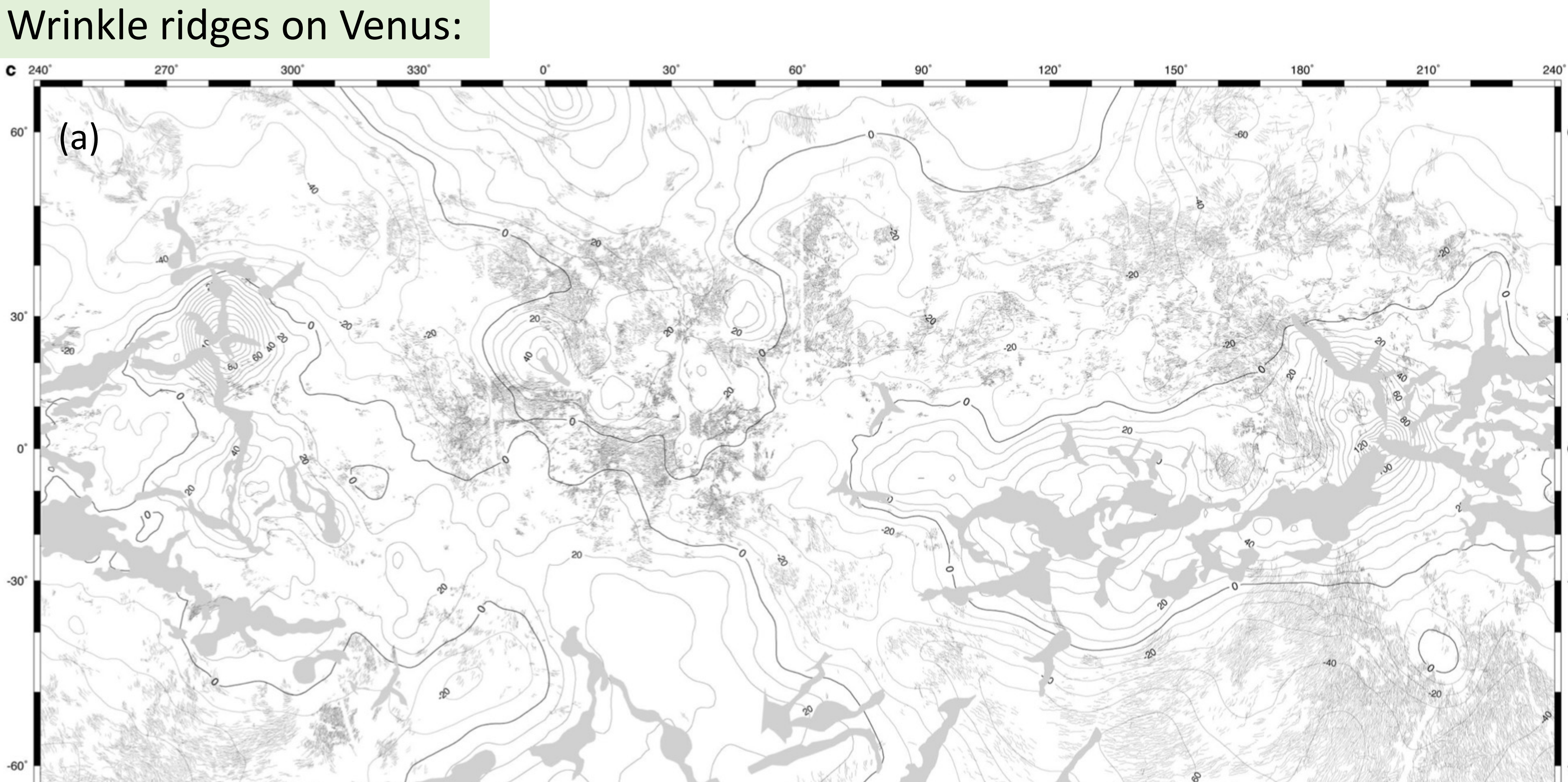
2. Limit lengths based on **plausible faulting depth,** D.

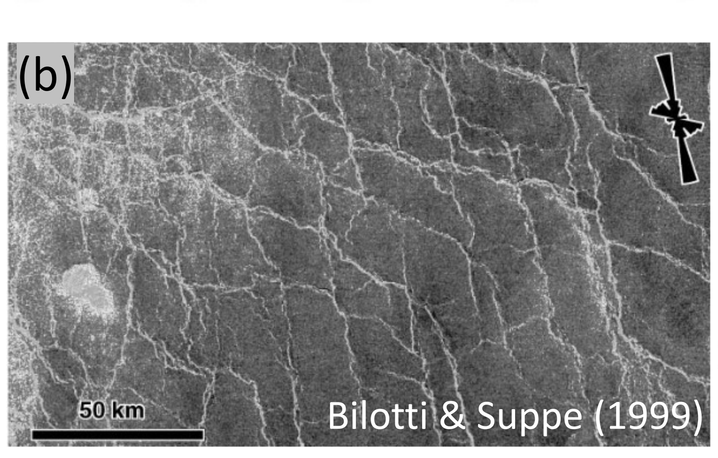
$$D = \frac{C_1 L^{2/3}}{\cos\theta}$$

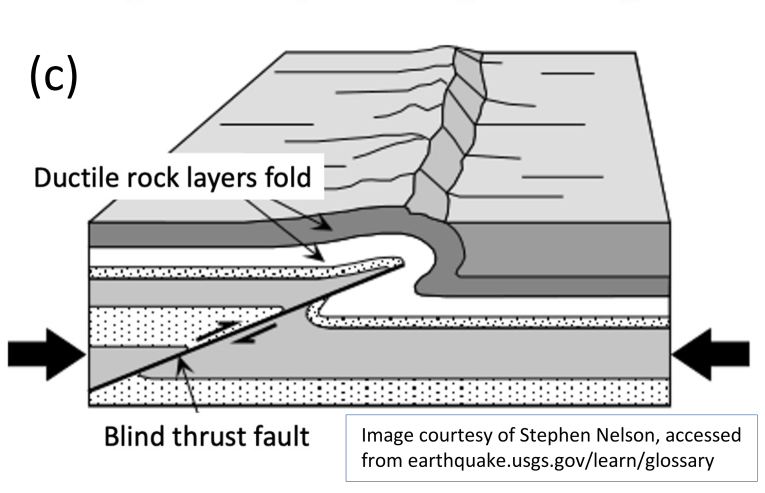
θ = fault dip, 30°

Equation based off Leonard (2010)

Wrinkle ridges on Venus:

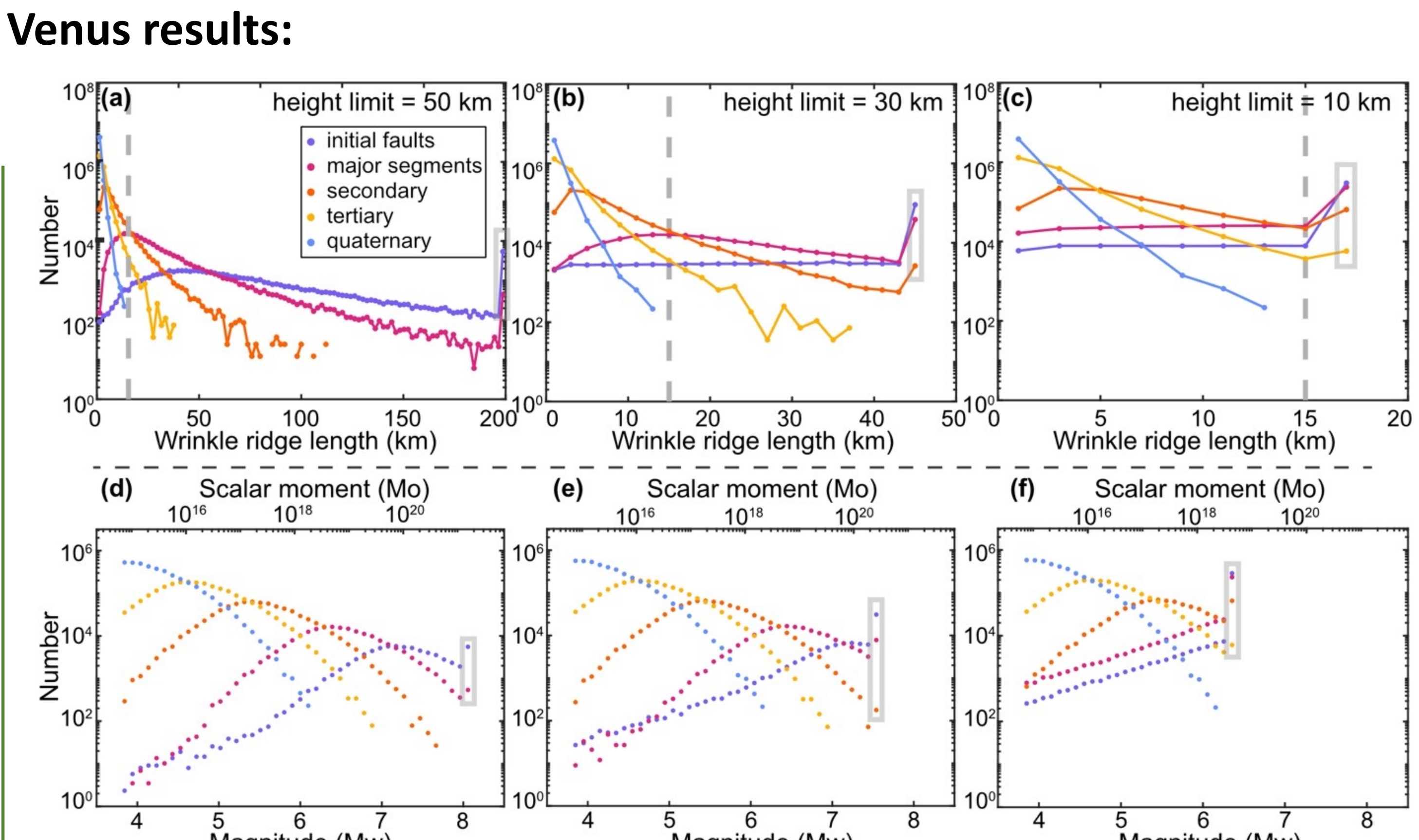






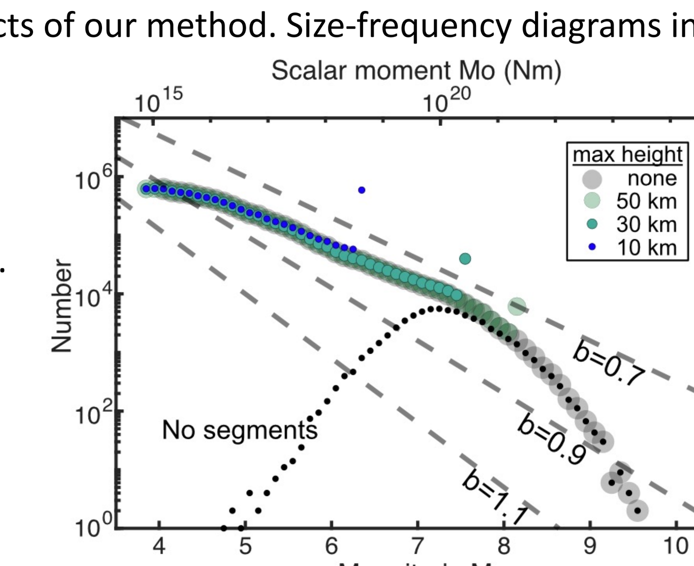
Bilotti & Suppe mapped 86,000 wrinkle ridges at a global scale (a). Wrinkle ridges appear in synthetic aperture radar (SAR) imagery as radar-bright, sinuous lineations (b). They are interpreted as surface expressions of blind thrust faults, which form due to compression, represented by black arrows (c).

Venus results:



Above: histograms of wrinkle ridge lengths segmented and limited by throws of 50 km (a), 30 km (b), and 10 km (c). Dashed grey line represents a reference 15 km length. Peaks corresponding to maximum allowed length (grey boxes) are artifacts of our method. Size-frequency diagrams in d-f.

Right: Size-frequency diagram for three maximum faulting heights of 50 km (translucent dark green), 30 km (teal), and 30 km (dark blue). Dashed lines represent slopes of typical terrestrial b-values for normal stress regimes (b=1.1), strike-slip regimes (b=0.9), and thrust regimes (b=0.7) (Schorlemmer et al, 2005) with arbitrary y-intercepts.



Publications:

- **Sabbeth**, L., Smrekar, S.E., Stock, J.M., AGU 2022, Talk, Abstract # 1097667, Predicting seismicity using fault scaling relationships: from Mars to Venus.
- **Sabbeth**, L., Smrekar, S.E., Stock, J.M., AGU 2021, Talk, Abstract # 834911, Predicting Venus' Seismicity from surface faulting.
- **Sabbeth**, L., Smrekar, S.E., Stock, J.M., Seismicity from Cerberus Fossae, Mars, based on fault scaling relationships, *anticipated submission 2022.*
- **Sabbeth**, L., Smrekar, S.E., Stock, J.M., Prediction for seismicity from Venusian wrinkle ridges based on fault scaling relationships, *anticipated submission 2022.*

Author Contact Information:

leah.sabbeth@jpl.nasa.gov | (626)344-5196

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

Poster Number: PRD-P#016