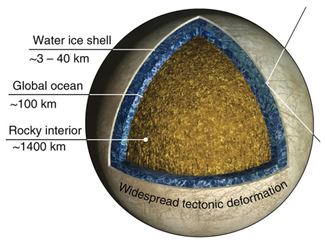
Band Strain and Morphology on Europa

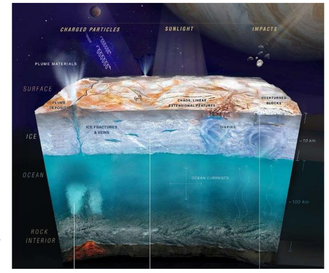
Relation of normal strain to overprinted terrain

Ian Jones (GEOL 393)

Advisor: Dr. Laurent Montési, Sophia Zipparo, Karla Núñez



Internal structure of Europa
Howell & Pappalardo (2020)
10.1038/s41467-020-15160-9

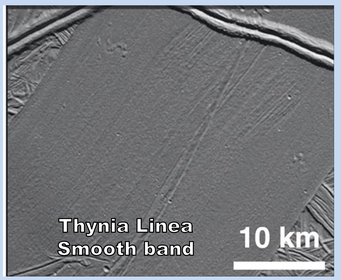


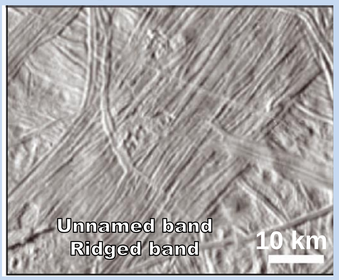
Geologic processes on Europa
Hand et al. (2022) 10.3847/PSJ/ac4493

Introduction

- Europa is a large, icy moon with a water ocean in orbit around Jupiter. Gravitational interactions between it, other moons, and Jupiter allow for enough tidal heating to create an ocean beneath a thin shell of ice (Cassen et al. 1979). The depth of the ocean is likely in excess of 30 km (Howell & Pappalardo, 2020).
- The ice shell is covered in linear features called *lineae*, but deficient in craters. This suggests that the surface has been hit by interplanetary objects for only a short amount of time, around 40 Myr. Some geologic processes wore away earlier craters. Band formation of bands may have resurfaced Europa.
- Bands are relatively wide lineae. They formed by a combination of extension and shear. Here I will determine if they also contain preexisting terrain that has been overprinted by the tectonic and volcanic band-forming processes. Zipparo (2022) showed that narrow lineae called ridges accommodated are made mostly of reworked pre-existing terrain.
- Three different types of bands are recognized
  - Smooth bands work like mid-ocean ridges and may form dominantly by the rapid extension of the ice shell
  - Ridged bands feature tilted blocks of ice that could be mainly pre-existing terrain. They may form when extension is limited and slow.
  - Lineated bands present an intermediate case.
- The ratio of width made by extension and by overprinting should be different in different band categories but has not yet been measured.

Figures 1 & 2: Smooth and Ridged Band





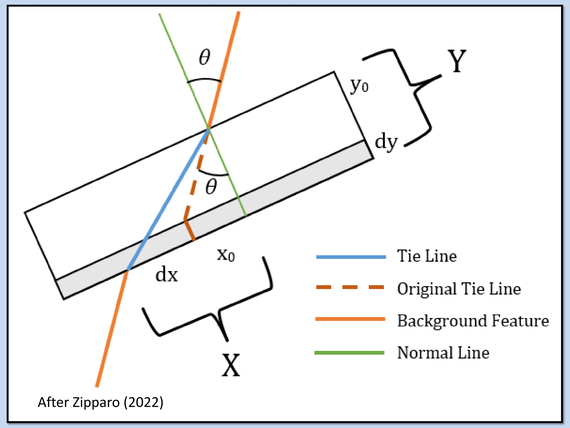
Hypothesis

The ratio of normal strain to overprinted material will be different between the different types of bands.

- Smooth bands are dominated by extension
- Ridged bands are dominated by overprinting

Analysis

Figure 3: Ideal band geometry



After Zipparo (2022)

Measure the way that pre-existing features are offset across a band.

- X Apparent offset
- Y Band width
- θ Pre-existing feature's crossing angle

Expected relations if the band has an initial width y_0, extension dy and shear dx

$$X = dx + y_0 \tan(\theta)$$
$$Y = dy + y_0$$

Least-square fit through measurements gives dx and y_0. Use an average band width $\bar{Y}$

Derived quantities for tectonic interpretation:

- Extension: $dy = \bar{Y} - y_0$
- Shear strain: $\gamma = \frac{dy}{y_0}$
- Normal strain: $\epsilon = \frac{dx}{y_0}$
- Fraction of pre-existing material: $f = \frac{y_0}{\bar{Y}}$

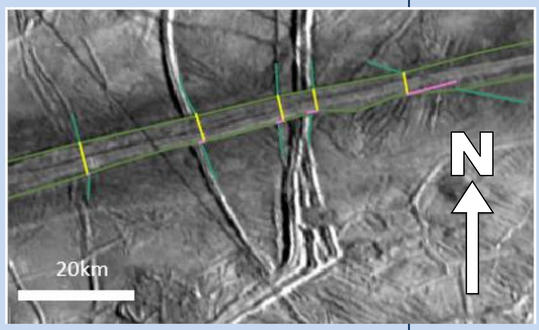
Data Collection

Figure 3: Example of Minos Linea

- Minos Linea outlined in green
- Feature outlines in blue-green
- Width of band in yellow
- Offset of feature in pink

Mapping conducted using ArcGIS at a scale of 1:500,000. Figure 3 is zoomed in for clarity

Minos Linea is a ridged band. We expect a large pre-existing material fraction f.



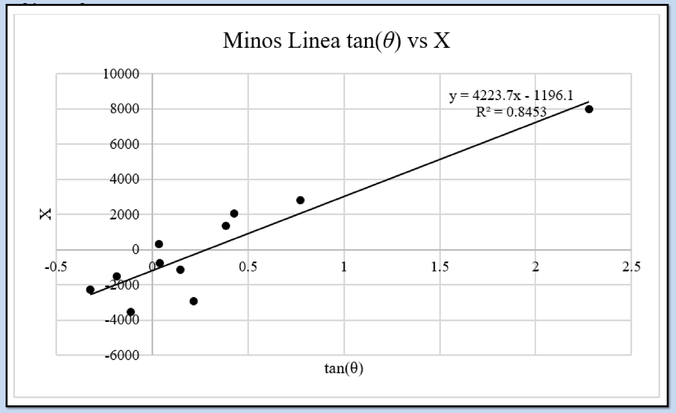
Uncertainty

- Mapping uncertainty set to 400 m based on the image resolution (1.75*resolution)
- Calculate the standard deviation σ_Y of the measured band widths
- Curve fitting by χ^2 minimization provides standard deviations for the fitting parameters σ_{dx} and σ_{y_0}
- Uncertainty is propagated to the derived quantities:

$$\sigma_{dy} = \sqrt{\sigma_Y^2 + \sigma_{y_0}^2}$$
$$\sigma_\gamma = \gamma \sqrt{\left(\frac{\sigma_{dy}}{dy}\right)^2 + \left(\frac{\sigma_{y_o}}{y_0}\right)^2}$$
$$\sigma_\epsilon = \epsilon \sqrt{\left(\frac{\sigma_{dx}}{dx}\right)^2 + \left(\frac{\sigma_{y_o}}{y_0}\right)^2}$$
$$\sigma_f = f \sqrt{\left(\frac{\sigma_{y_o}}{y_0}\right)^2 + \left(\frac{\sigma_Y}{Y}\right)^2}$$

Results

Figure 4: Offsets and crossing angles measured for Minos Linea and line



Results and derived quantities

- $dx = -1200 \pm 130$ m
- $y_0 = 4200 \pm 180$ m
- $\bar{Y} = 4600 \pm 900$ m
- $dy = 380 \pm 920$ m
- $\epsilon = 0.09 \pm 0.22$
- $\gamma = -0.26 \pm 0.05$
- $f = 0.92 \pm 0.18$
- The large pre-existing fraction is consistent with the proposed origin of ridge bands like Minos Linea as consisting mainly of reworked material with little extension.

Outlook

Future data collection will include

- Further examples of ridged bands
- Smooth bands
- Comparison of existing fractions

It is expected that smooth bands will have low f and further ridged bands will have high f.

Resources & References

Software: ArcGIS Pro 2.8.0 and Excel

Dataset: Becker, T., 2020, Europa Voyager - Galileo SSI global mosaic 500m V2: USGS Astrogeology Science Center, Europa Voyager - Galileo SSI Global Mosaic 500m v2. Available from: https://astrogeology.usgs.gov/search/map/Europa/Voyager-Galileo/Europa_Voyager_GalileoSSI_global_mosaic_500m (Accessed 2 May 2023)

Cassen, P., Reynolds, R.T., Peale, S.J., 1979. Is there liquid water on Europa? Journal of Geophysical Research. 6, 731-734. https://doi.org/10.1029/GL006i009p00731

Howell, S. M., and Pappalardo, R. T., 2018. Band formation and ocean-surface interaction on Europa and Ganymede. Geophysical Research Letters, 45, 4701– 4709. https://doi.org/10.1029/2018GL077594

Zipparo, S., 2020, strain analysis of ridges on Europa, senior thesis, University of Maryland Dpt. of Geology