On the mechanical origin of two-wavelength tectonics on Ganymede

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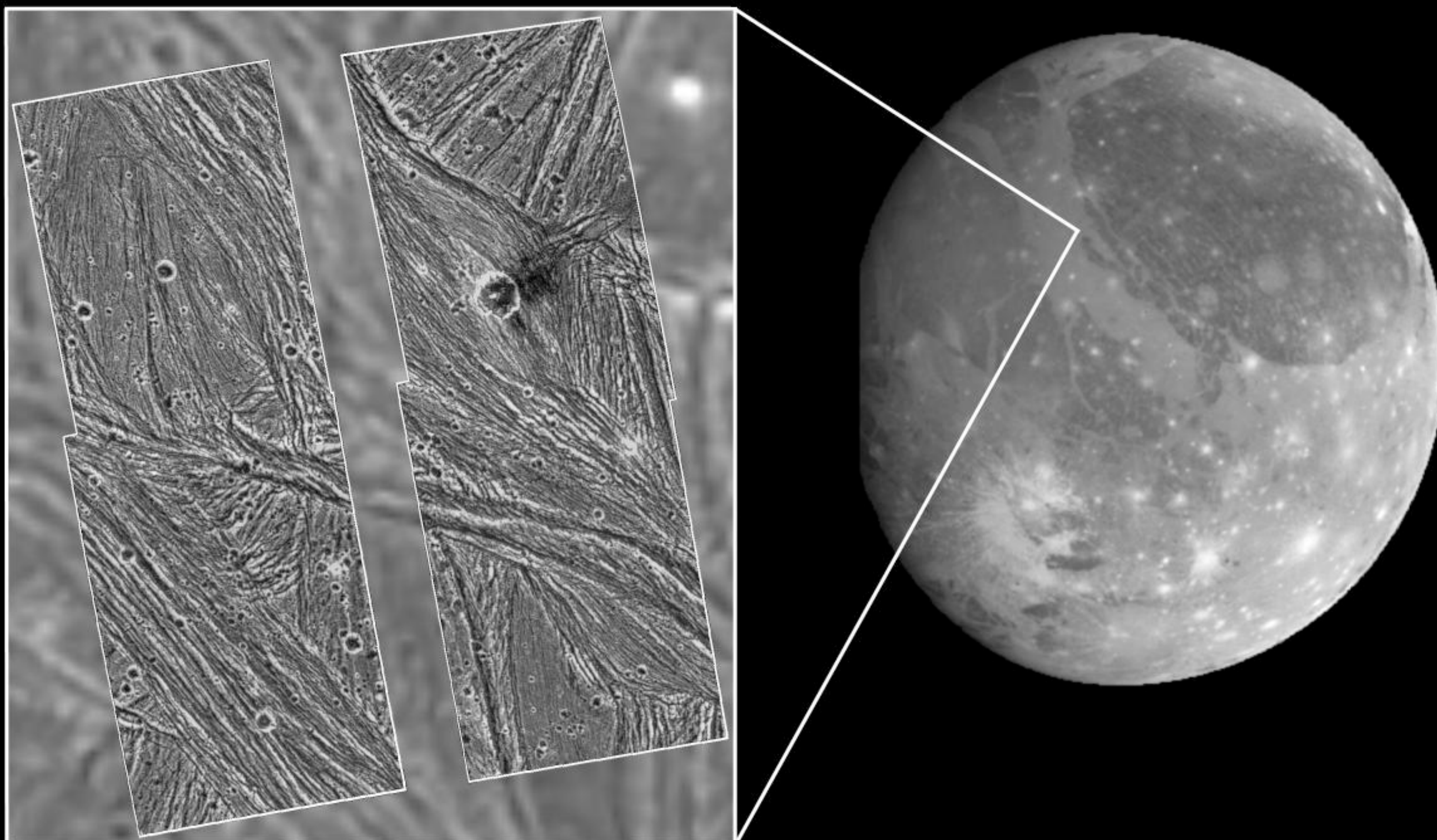
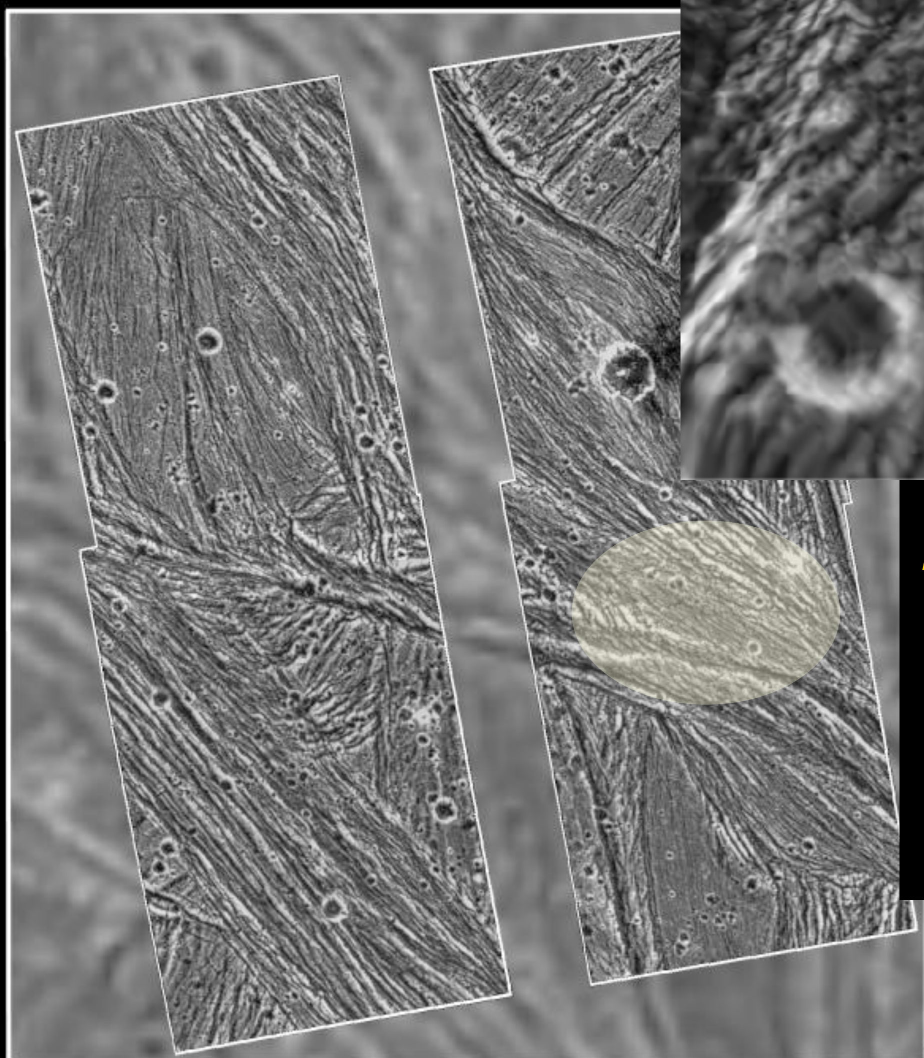
Overview

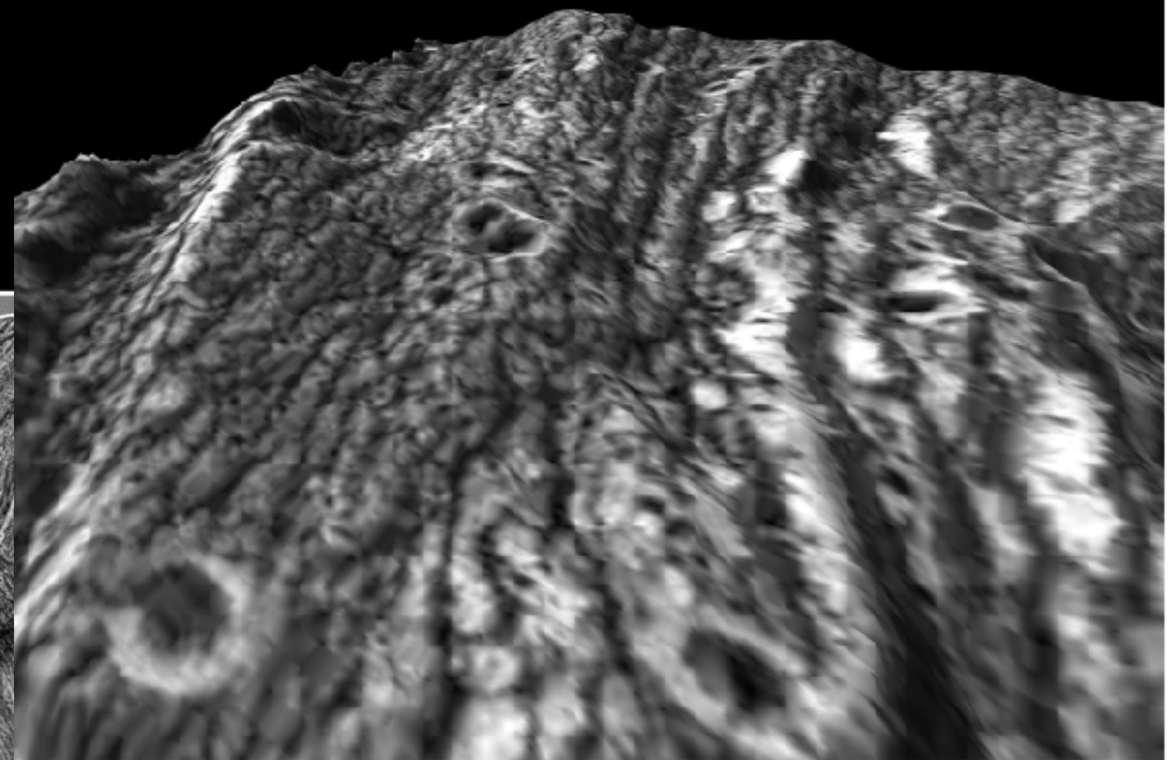
- Tectonic Wavelengths
  - Fault spacing
  - Topographic undulations
- Necking
  - Requires residual strengths
- Faulting
  - Localization instability
  - Graben morphology
  - Alternative origin for undulations

Uruk Sulcus



Uruk Sulcus





High strained area

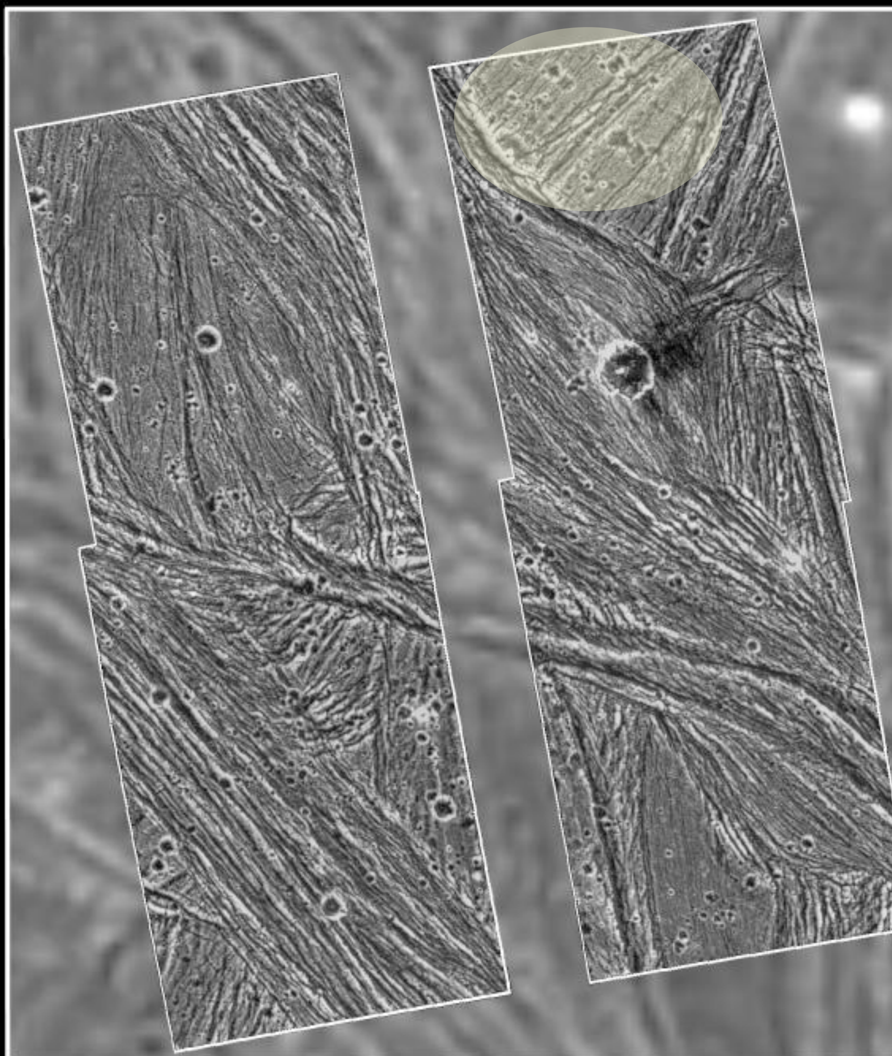
Fault spacing: 1 to 2 km

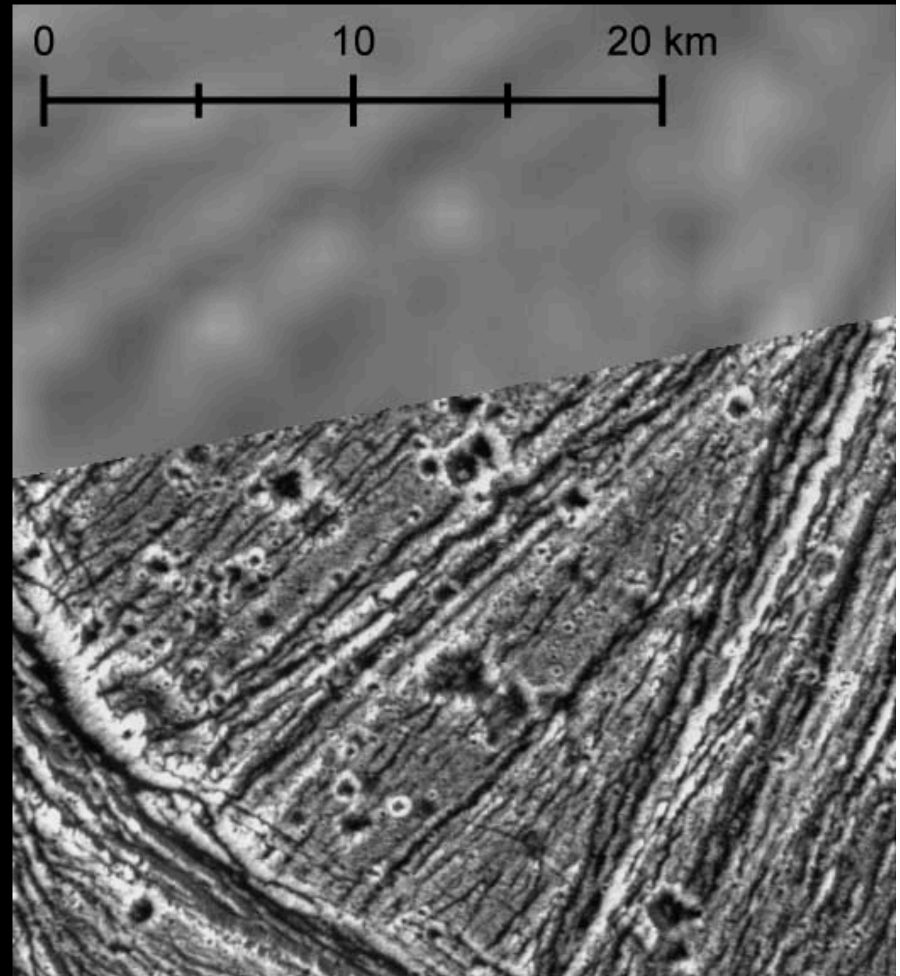
Undulation wavelength: 5 to 10 km

Collins et al., 1997

Patel et al., 1999

Uruk Sulcus





Low strain area

Fault spacing: 1 to 2 km

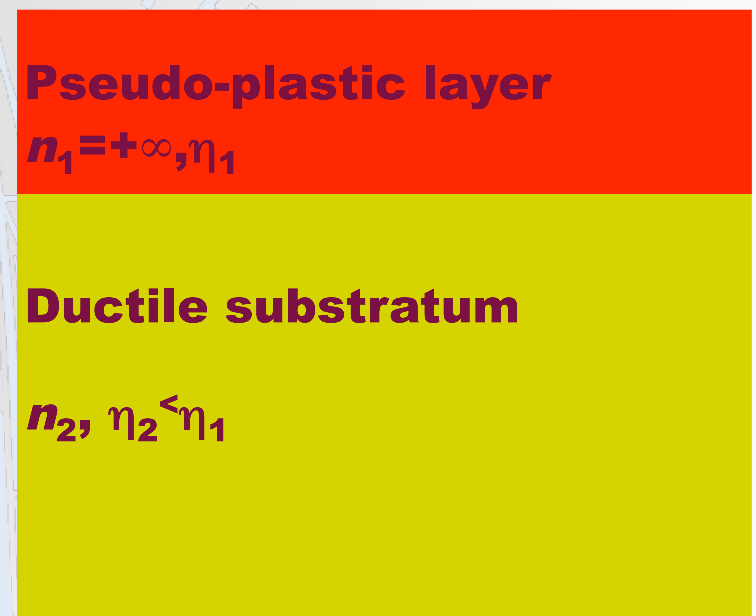
Graben spacing: ~10 km

Necking on Ganymede

- Fink and Fletcher LPSC 1981
  - Necking can produce topographic undulations with wavelength ~20 km
- Herrick and Stevenson, 1990
  - Growth rate of necking is too low to develop over reasonable time scale
- Dombard and McKinnon, 2001
  - Growth rate is OK if updated rheologies and lower surface temperature are used

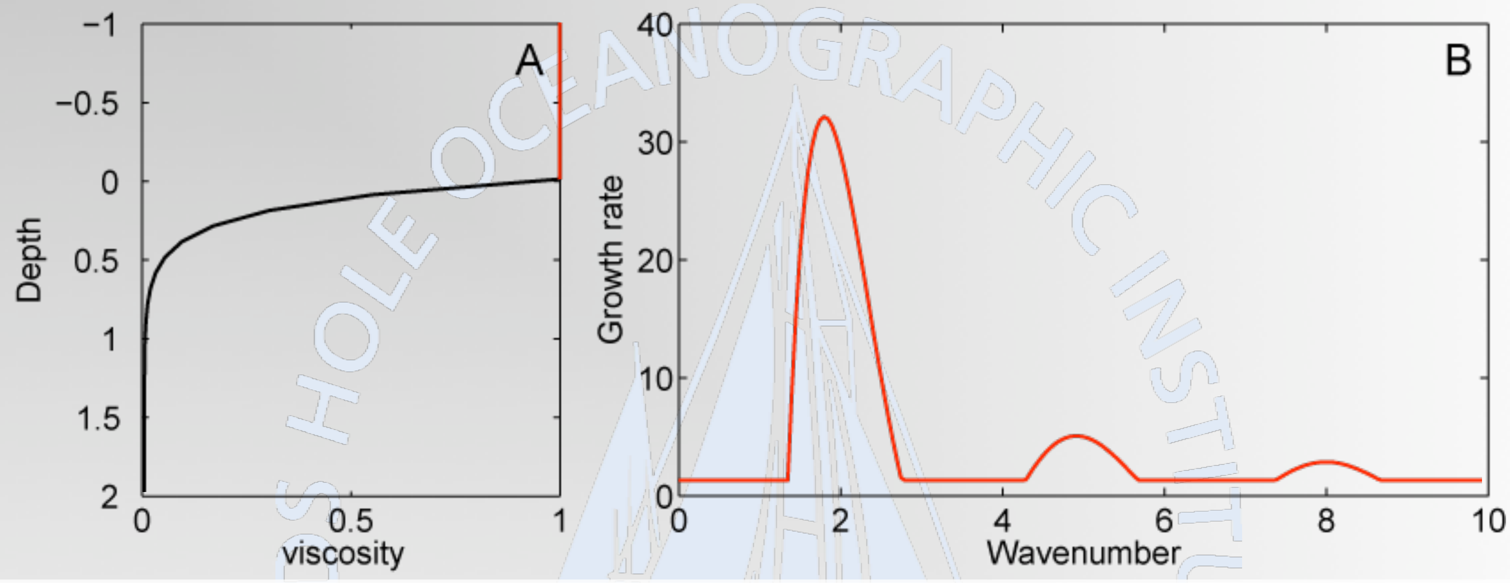
Necking primer

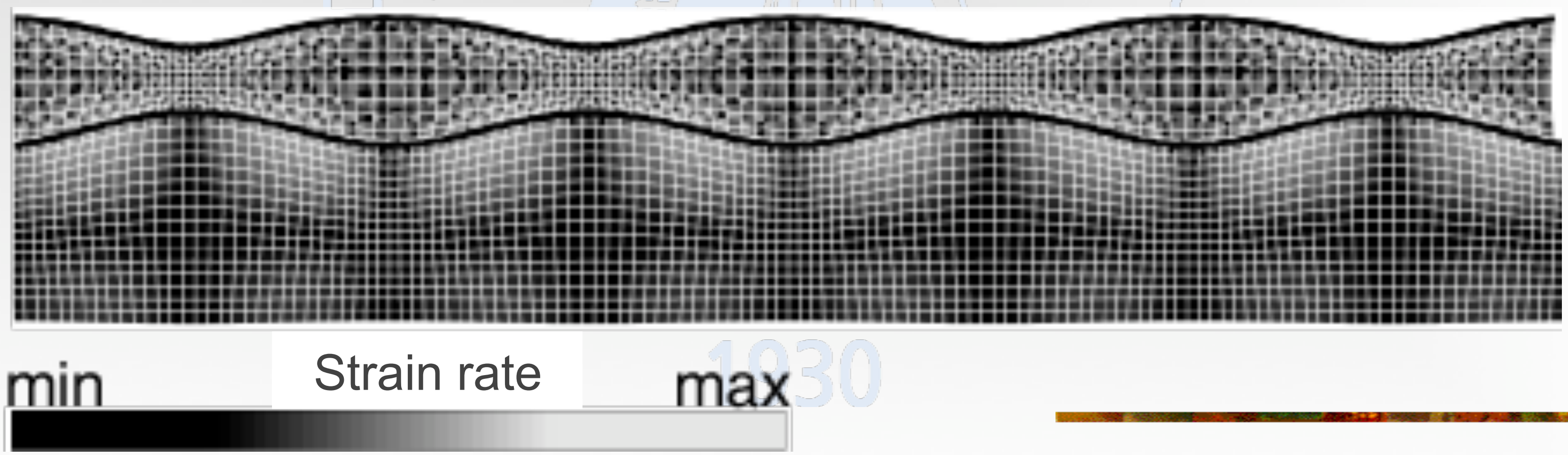
- Layered structure
- Power law rheologies
- Requires strength contrast
- Wavelength scales with depth to brittle-ductile transition
- Growth rate depends on strength contrast



Fletcher, 1974; Smith 1977; Fletcher and Hallet, 1983

Necking: Growth Spectrum

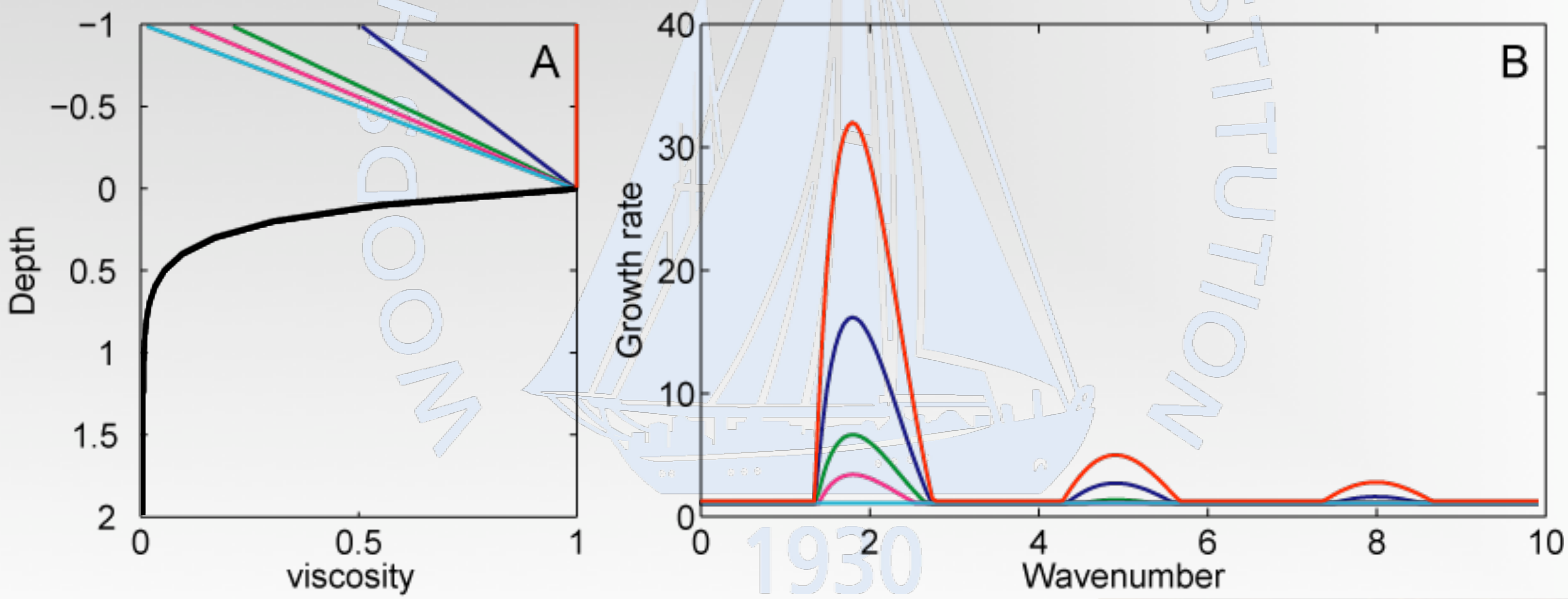




Deformation pattern of the necking instability

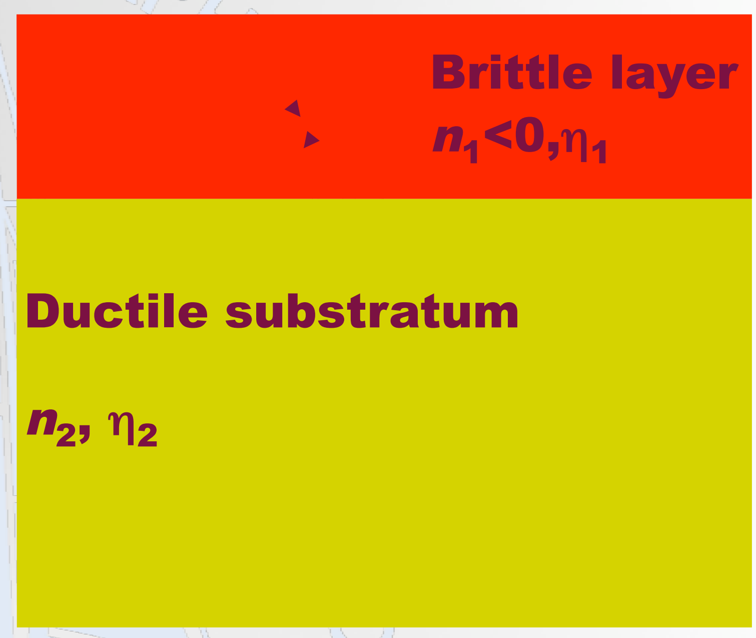
Necking revisited

- Classical models use constant strength brittle layer
- Growth rate decreases with strength at the surface
- *Necking requires residual near-surface strength*



Localization instability

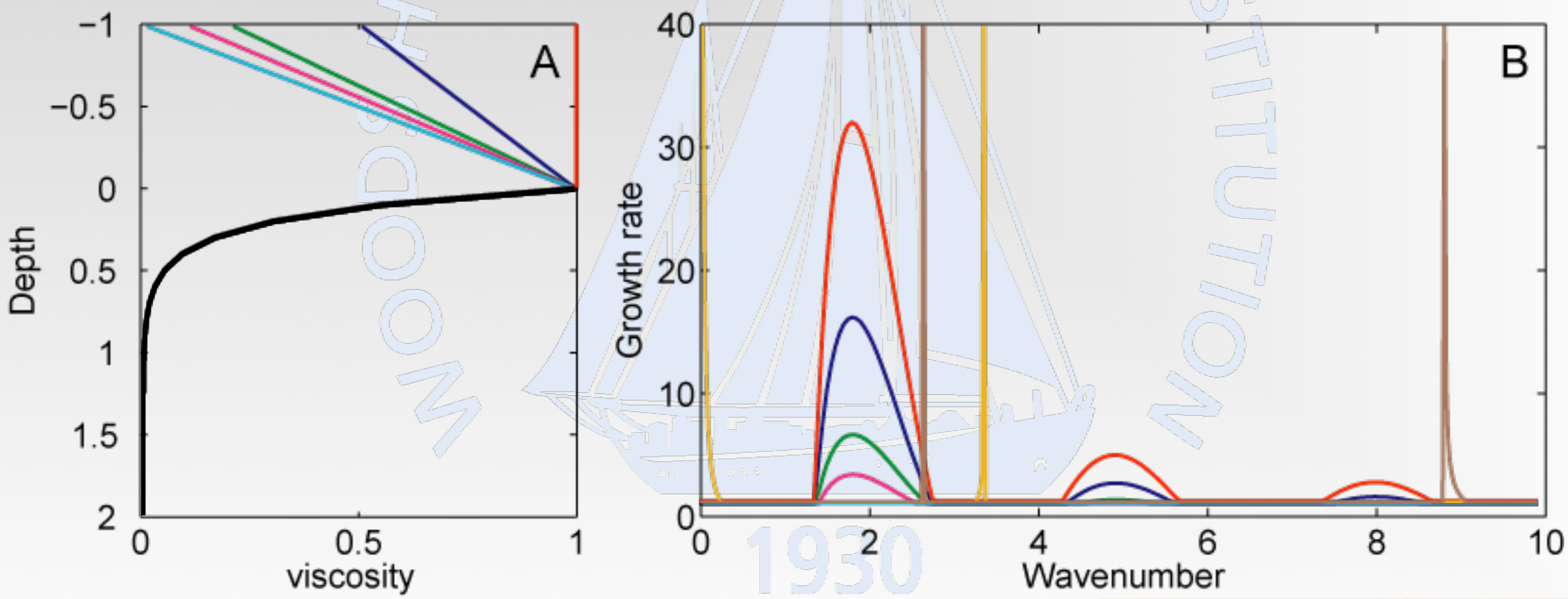
- Requires contrast in material properties with strain rate weakening in brittle layer
- Wavelength scales with depth to brittle-ductile transition
  - Depends on rate of weakening
- Infinite growth rate



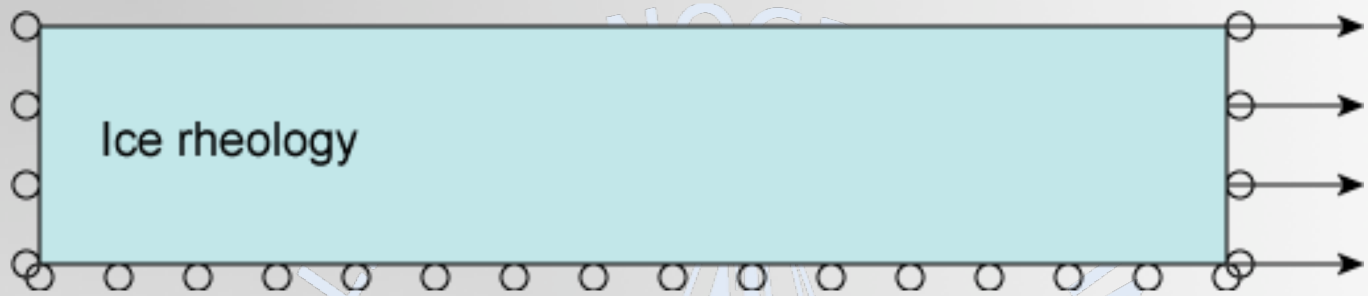
Montési and Zuber, 2003

Growth spectrum with localization

- Localization produces infinite growth rate peaks
- Wavelength of peaks depends on rate of weakening
- Question: What is the expression of this instability?

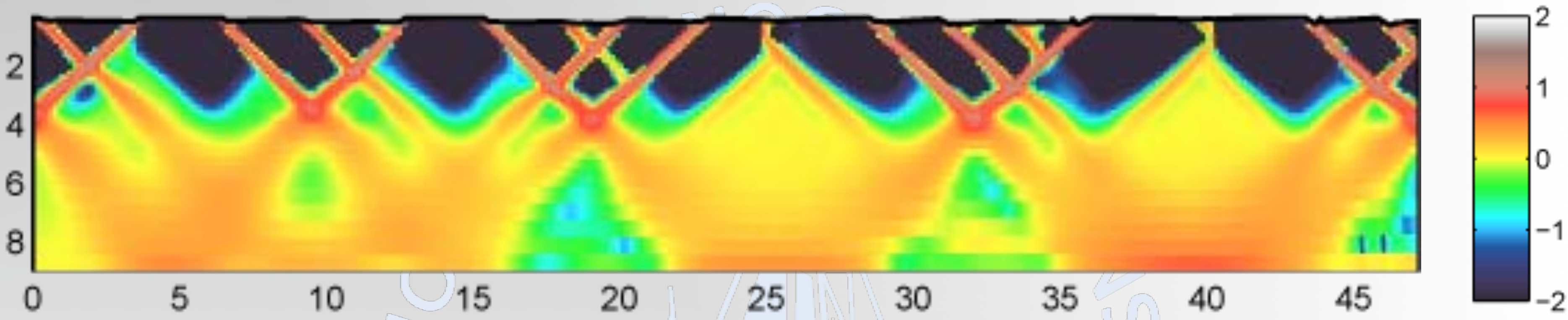


Numerical model

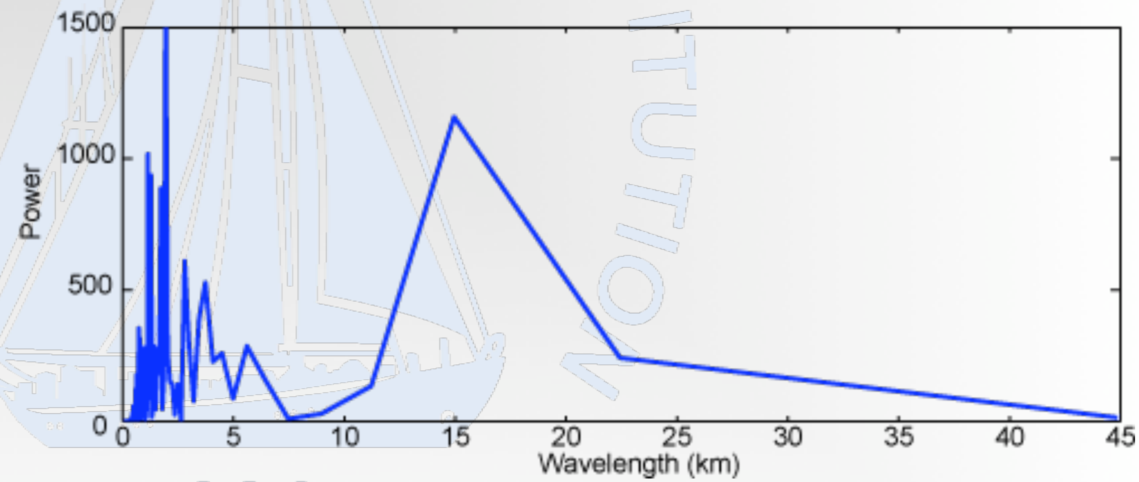


- Finite Elements Code LAYER (Neumann and Zuber, 1995)
- 45x9 km box
- 300x40 elements 150 m wide, variable height
- Ice rheology
  - Brittle law (Beeman et al., 1988) with strain-rate weakening
  - Ductile laws from Goldsby and Kohlstedt 2001
- Exponential thermal profile
- Extension rate: $10^{-15} s^{-1}$
- Instantaneous solution, stretched 5%

Faulting at two wavelengths

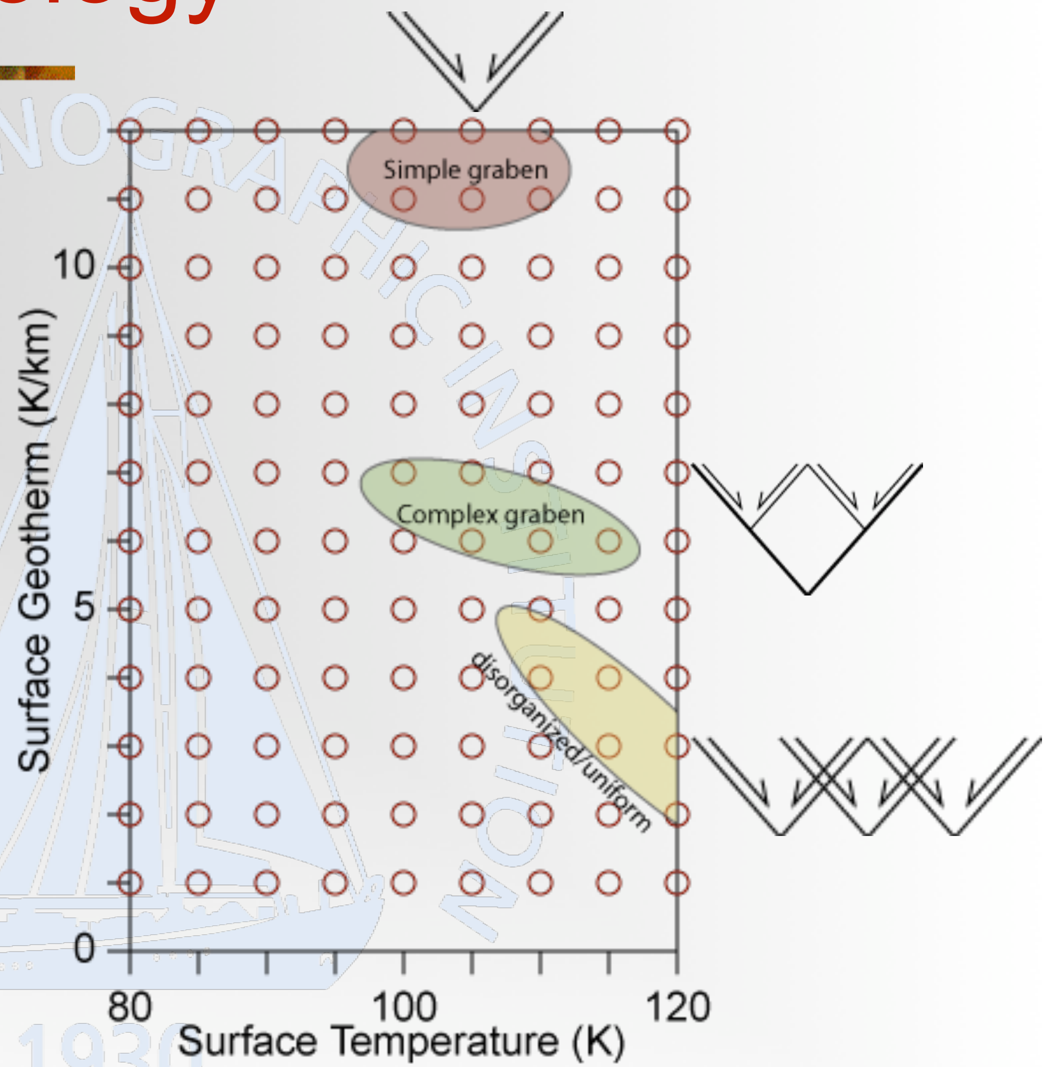


- Brittle law
  - $\sigma=\sigma_0[1-C \ln(\dot{\varepsilon}/\dot{\varepsilon}_0)]$
  - C=0.15
- Thermal structure:
  - 110 K at the surface
  - Geotherm 6 K/km
- Wavelengths
  - Faulting: 1.8 km
  - Graben spacing influenced by model size (here 15 km)



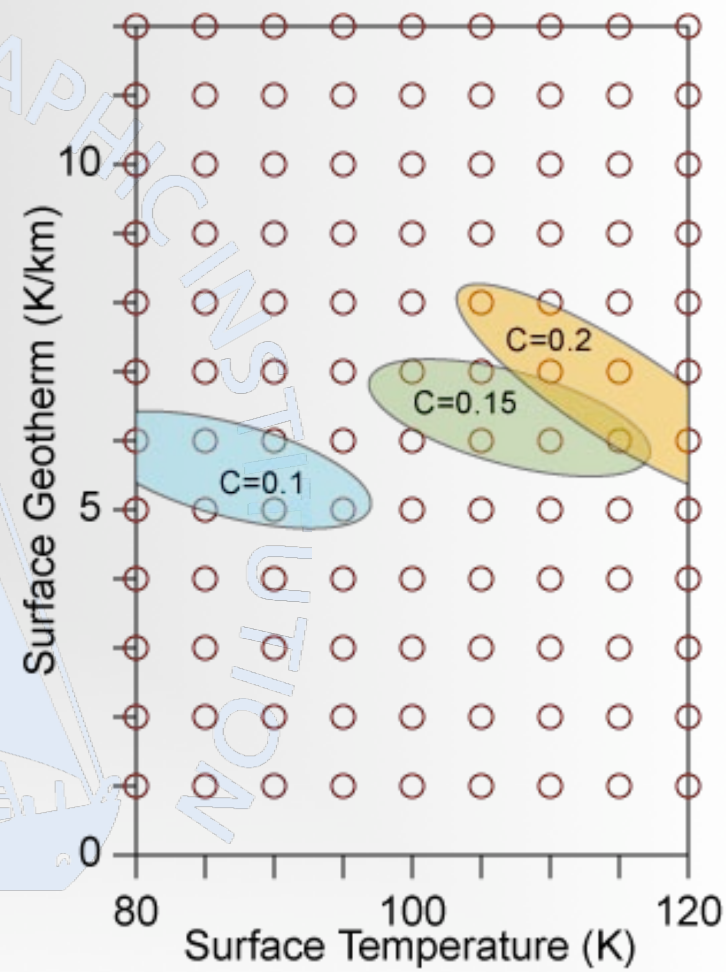
Structure morphology

- Brittle law
  - $\sigma=\sigma_0[1-C \ln(\varepsilon/\varepsilon_0)]$
  - C=0.15
- Various graben morphology for fault spacing between 1 and 2 km
- Uruk Sulcus low strain area displays complex grabens
  - Surface temperature between 100 and 115K
  - Geotherm between 5 and 7 K/km
  - Heat flow between 30 and 40 mW/m^2



Thermal structure

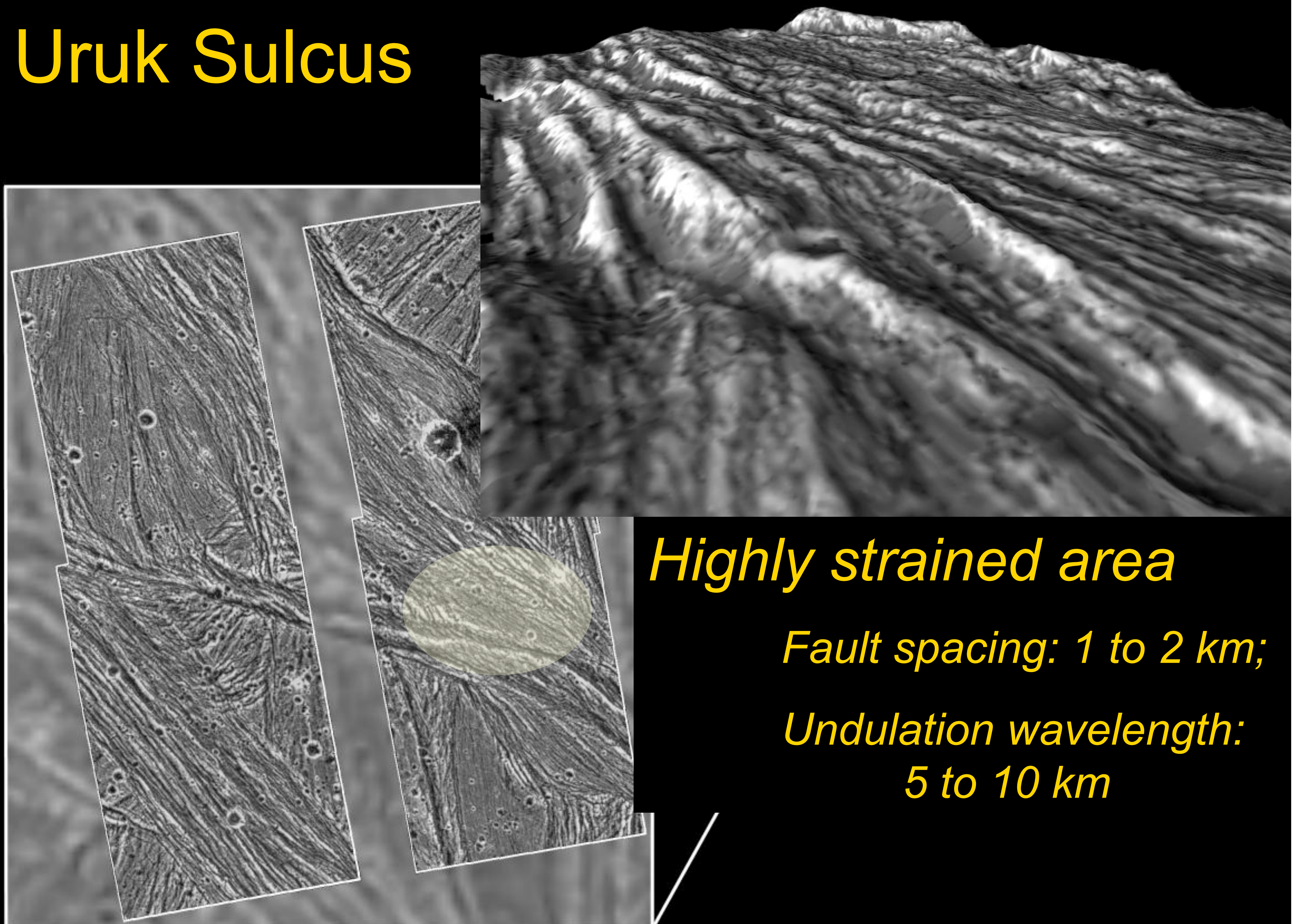
- Complex graben with 1-2 km fault spacing form for geotherm around 6±1 K/km
  - Heat flow ~33 mW/m^2
- Surface temperature depends on rate of weakening, but close to current temperature
  - Warning, colder conditions may be needed if less intense localization (but shear zones less diffuse)
- Additional variables
  - Strain rate
- Long wavelength depends on the thickness of the model



Conclusions

- Faulting occurs with regular spacing
  - Several graben morphologies observed in numerical simulations
  - Complex grabens with 1-2 km fault spacing obtained for surface temperature above 100 K with surface geotherm around 6 K/km (heat flow ~ 35 mW/m^2)
- Long wavelength undulations have separate origin
  - Necking if there exists a residual near-surface strength
  - Long range fault interaction if there is a detachment
  - Finite strain effect

Uruk Sulcus

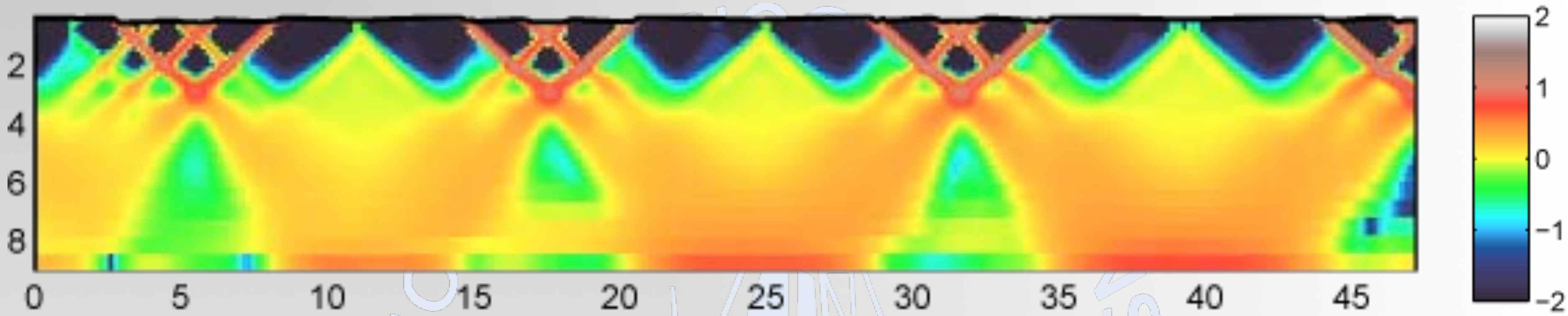


Highly strained area

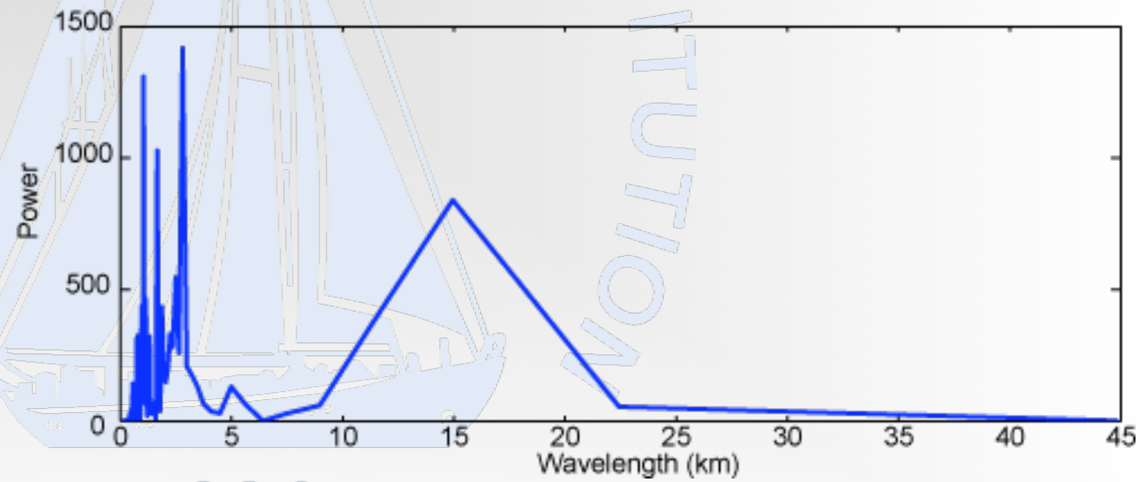
Fault spacing: 1 to 2 km;

Undulation wavelength: 5 to 10 km

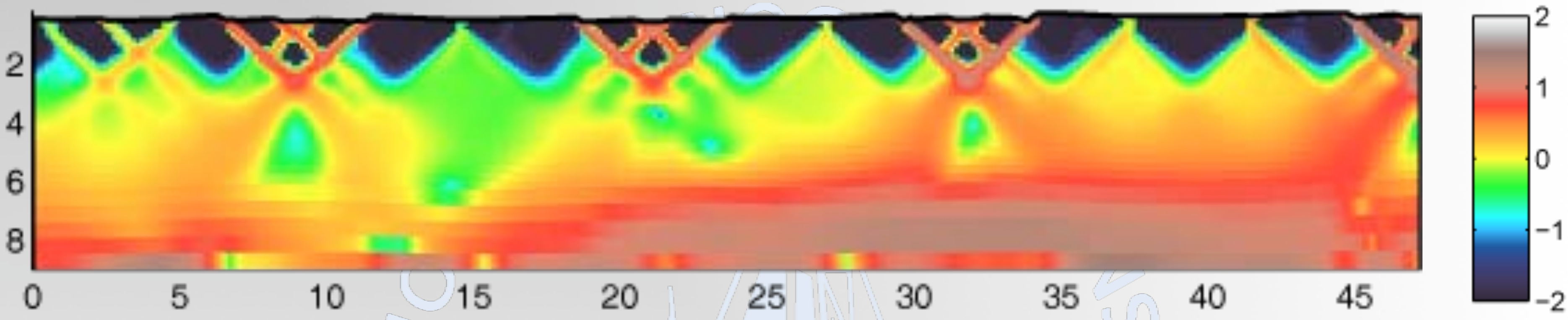
Faulting at two wavelengths



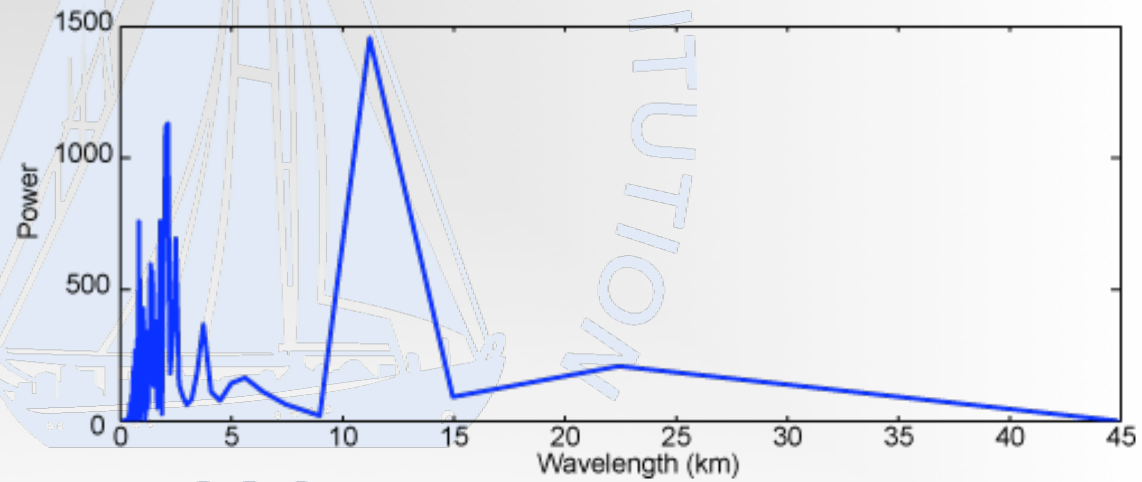
- Brittle law
  - $\sigma = \sigma_0[1 - C \ln(\dot{\varepsilon}/\dot{\varepsilon}_0)]$
  - C=0.2
- Thermal structure:
  - 120 K at the surface
  - Geotherm 6 K/km
- Wavelengths
  - 2.5 km
  - 15 km



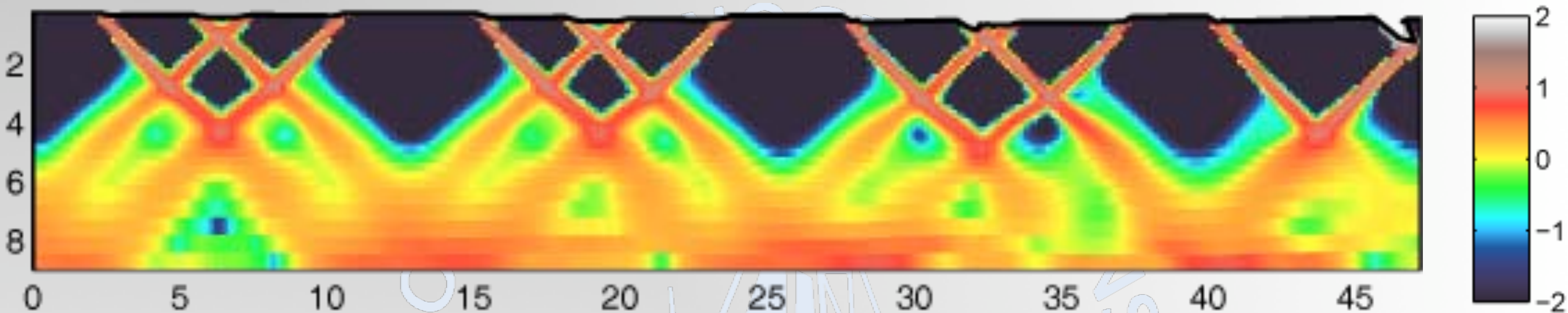
Faulting at two wavelengths



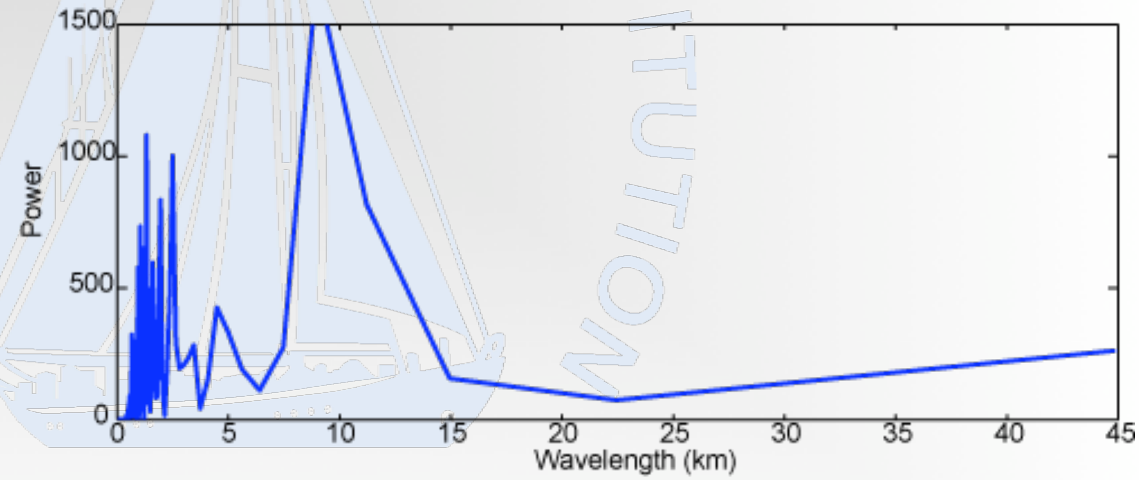
- Brittle law
  - $\sigma=\sigma_0[1-C \ln(\dot{\varepsilon}/\dot{\varepsilon}_0)]$
  - C=0.2
- Thermal structure:
  - 120 K at the surface
  - Geotherm 7 K/km
- Wavelengths
  - 1.4 km
  - 12 km



Faulting at two wavelengths

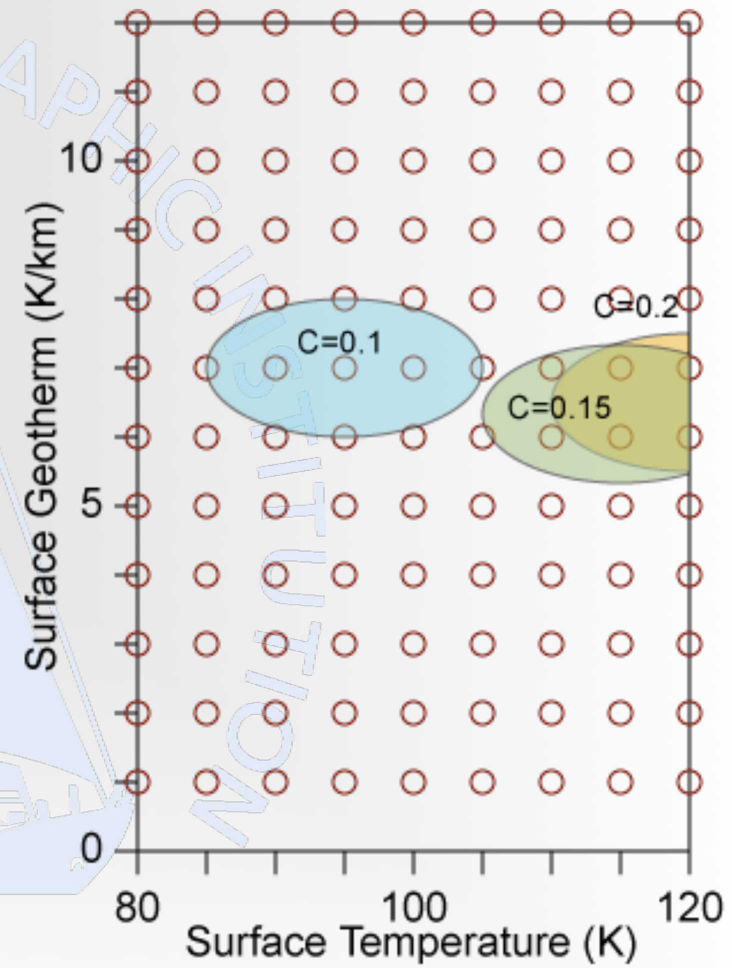


- Brittle law
  - $\sigma=\sigma_0[1-C\ \ln(\dot{\varepsilon}/\dot{\varepsilon}_0)]$
  - C=0.1
- Thermal structure:
  - 90 K at the surface
  - Geotherm 7 K/km
- Wavelengths
  - 2 km
  - 9 km



Thermal structure

- Geotherm around 7±1 K/km
  - Heat flow ~35 mW/m^2
- Surface temperature depends on rate of weakening, but close to current temperature
  - Warning, colder conditions may be needed if less intense localization (but shear zones less diffuse)
- Additional variables
  - Strain rate
  - Thickness of the model



Conclusions

- Necking can produce long-wavelength undulations only if there exist a residual near-surface strength
- Faulting can develop at two wavelengths
  - Fault spacing controlled by localization instability
  - Graben spacing controlled by long-range fault interaction
- 2 km fault spacing and 10 km topographic undulatons obtained for surface temperature around 110 to 120 K with surface geotherm around 7 K/km (heat flow ~ 35 mW/m^2)