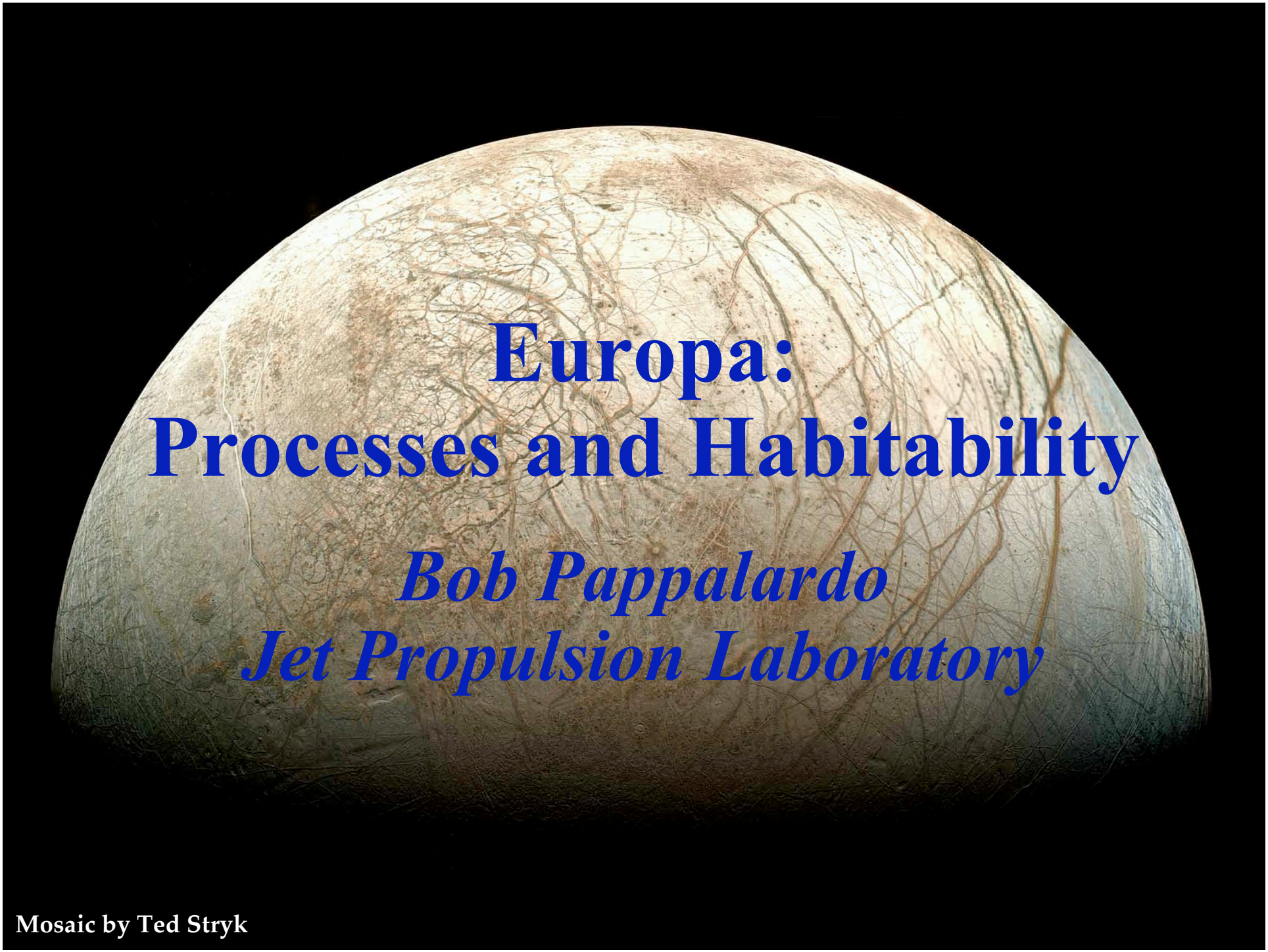
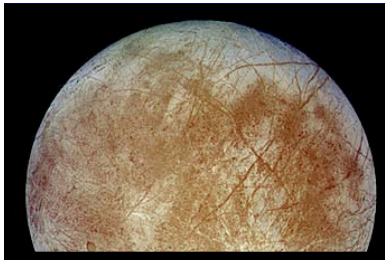
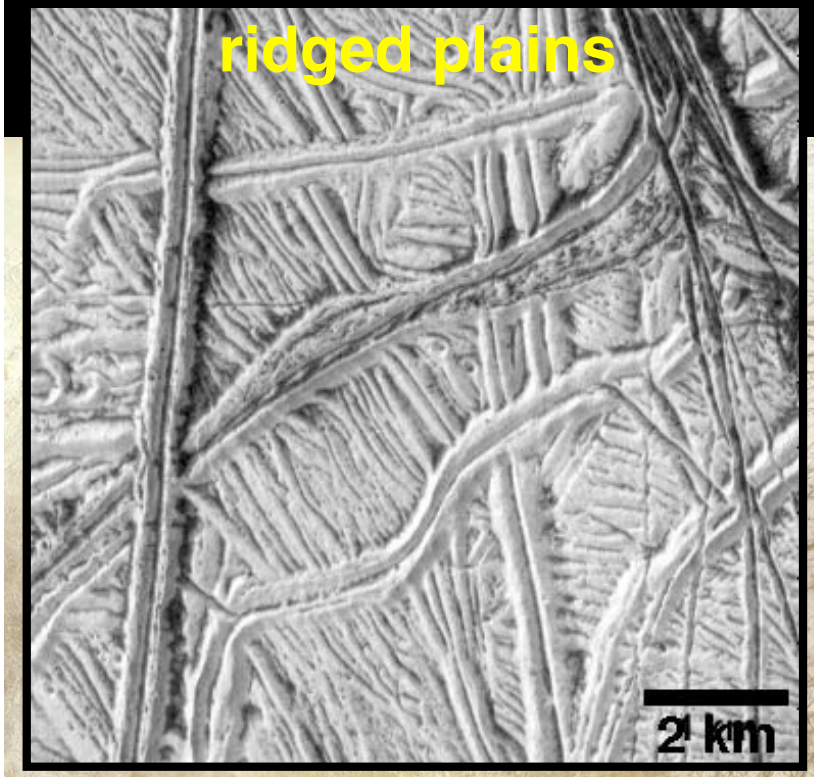
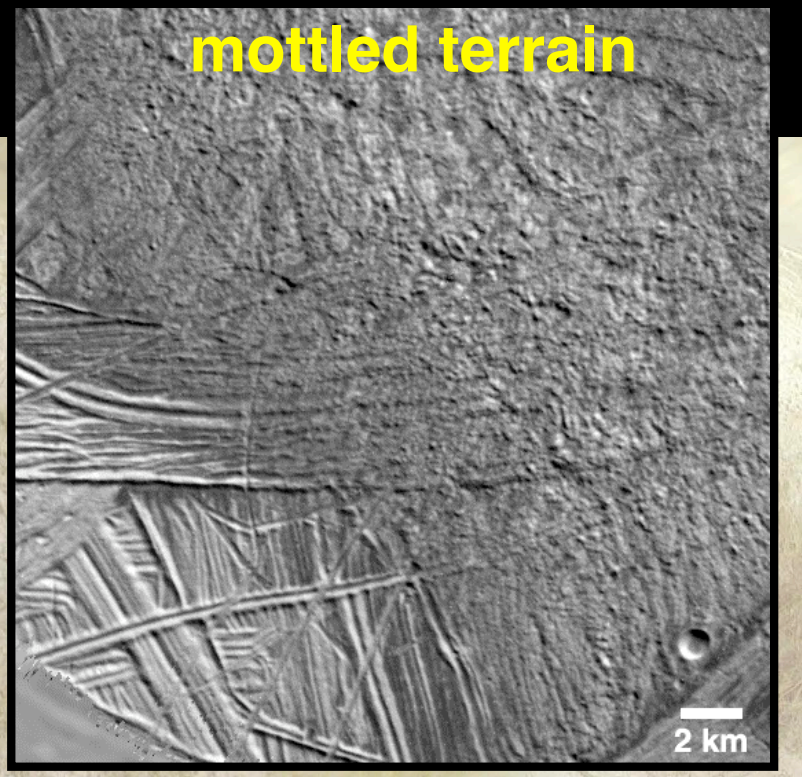

Europa:
Processes and Habitability
Bob Pappalardo
Jet Propulsion Laboratory
Mosaic by Ted Stryk



Europa: Complex Geology



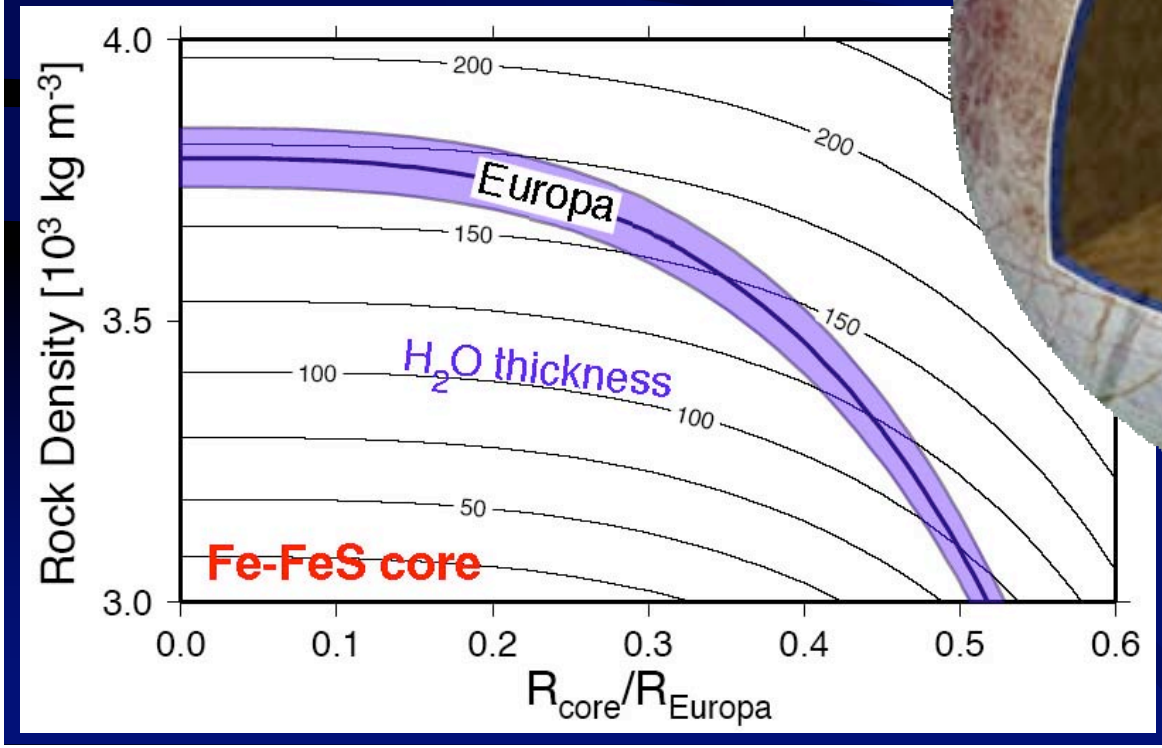


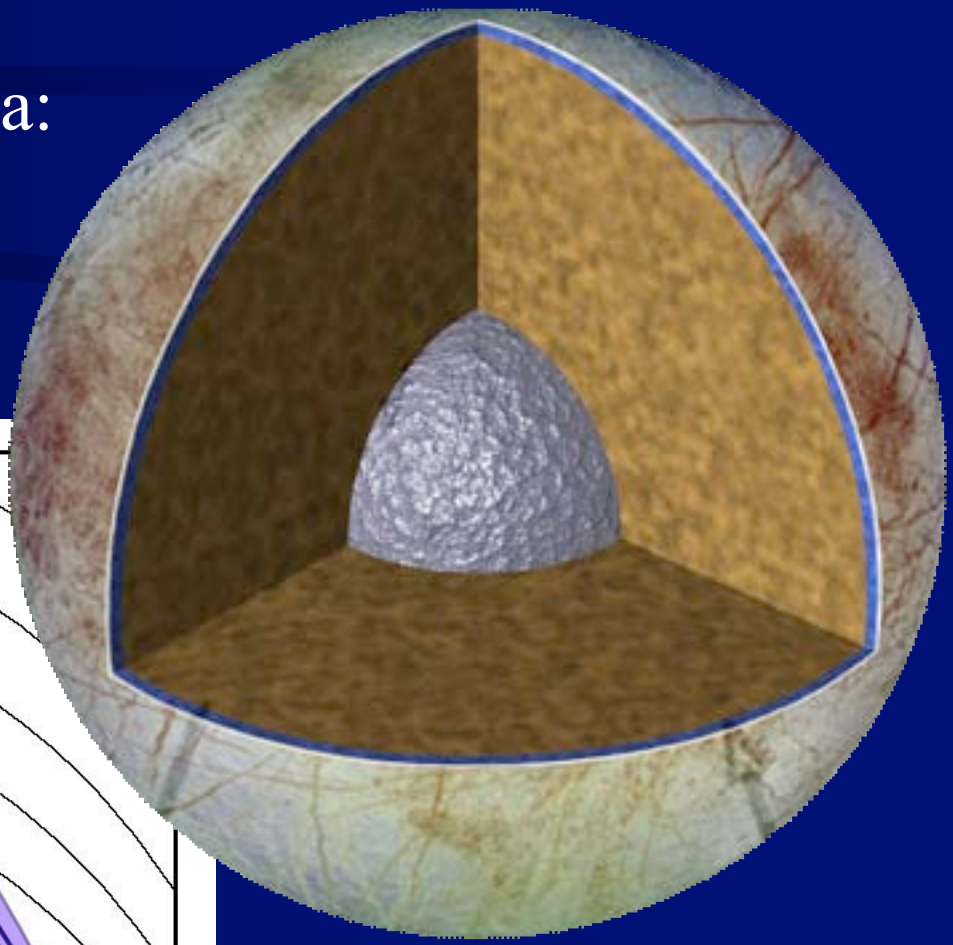
Mosaic by Steve Albers

Europa's Interior: Gravity Data

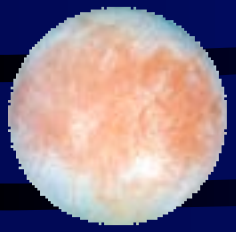
Axial moment of inertia from Doppler gravity data:

- $C/MR^2 = 0.346 \pm 0.005$
- H_2O-rich crust: ~80 - 170 km thick.



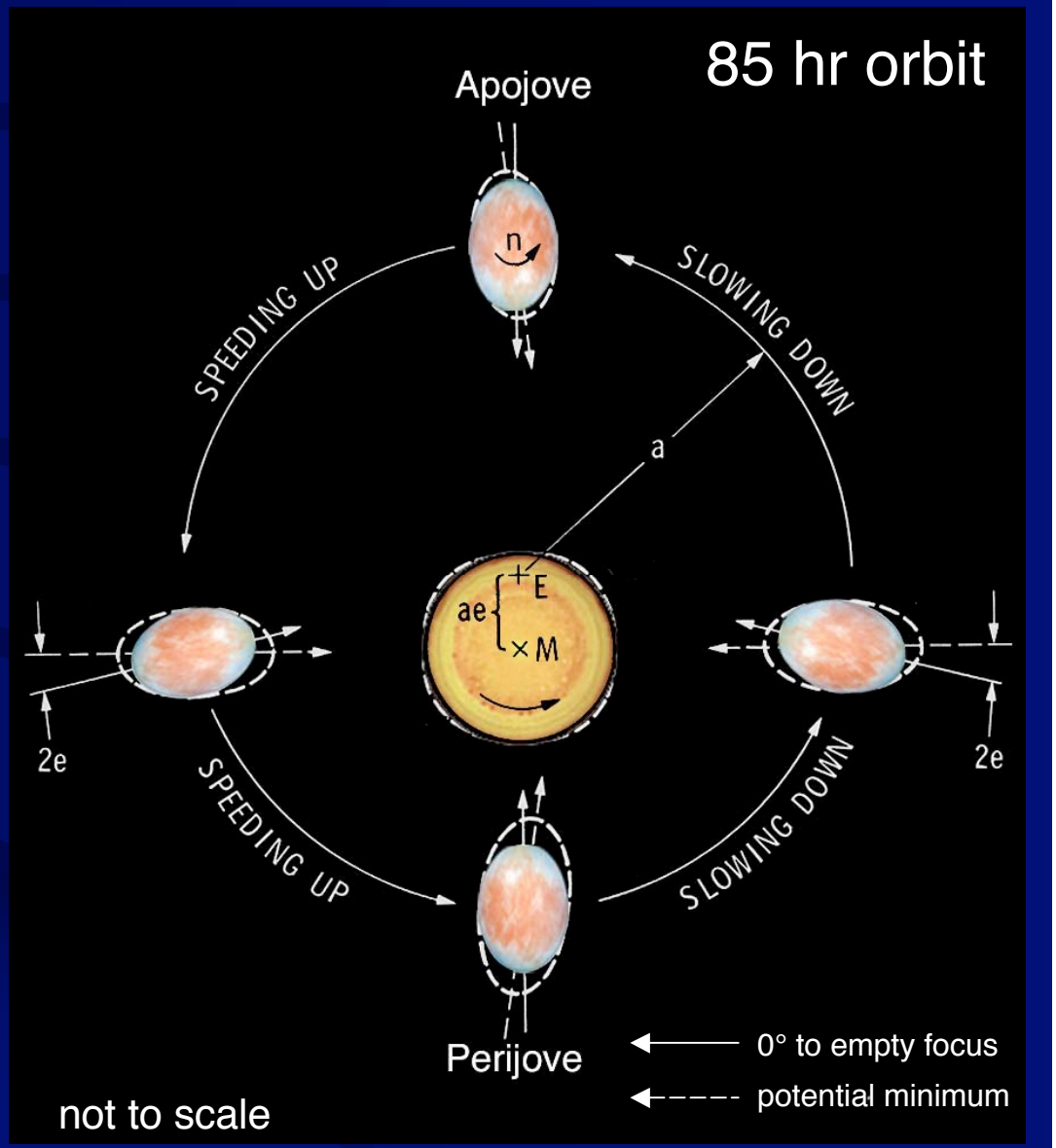


[Anderson et al., 1998]



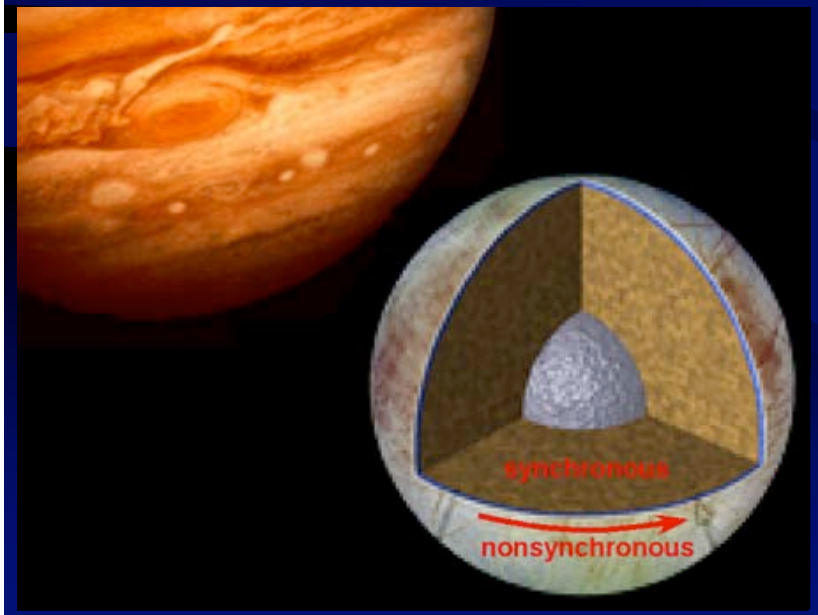
Europa's Eccentric Orbit

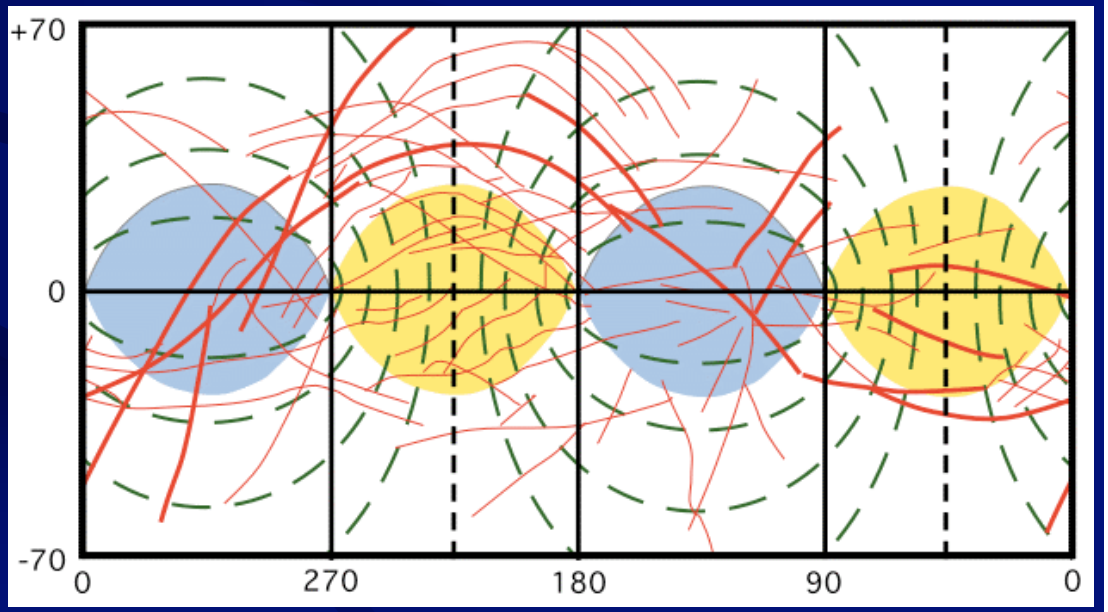
- Eccentric orbit (e = 0.01).
- Tide ~30 m if ice shell is decoupled by ocean.
- Libration (constant rotation rate; variable orbital speed).
- Tidal deformation dissipates energy: *tidal heating*.
- Misalignment of tidal bulge promotes *nonsynchronous rotation*.



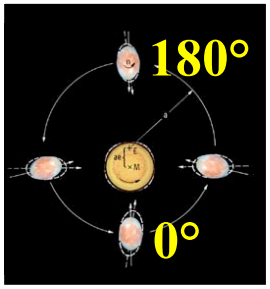
Europa Stress Mechanisms: Nonsynchronous Rotation Stress

- Nonsynchronous rotation is predicted if ice shell is decoupled from rocky mantle.
- Provides the best match to global lineament patterns.
- Suggests decoupling by liquid water.



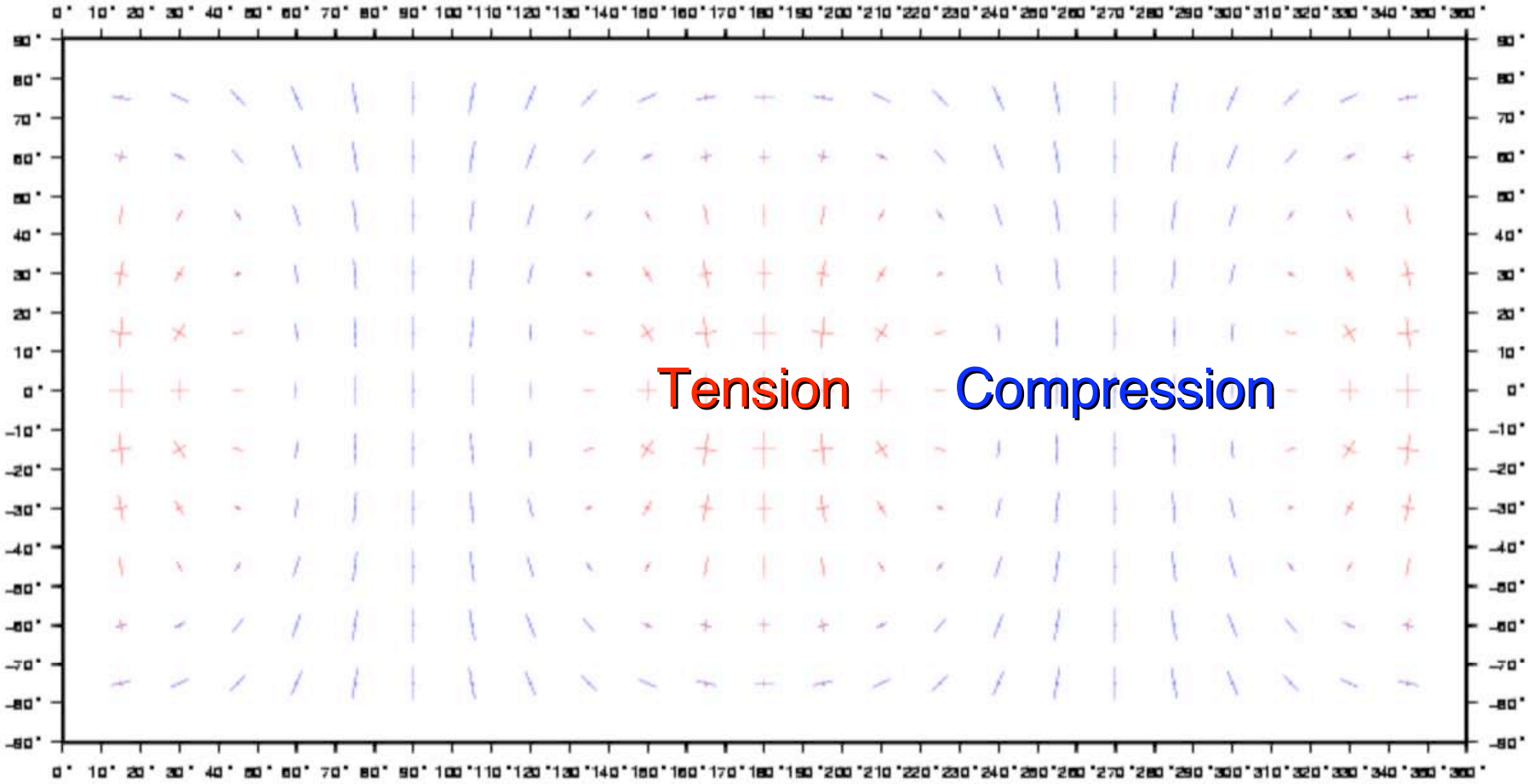


[McEwen, 1986]



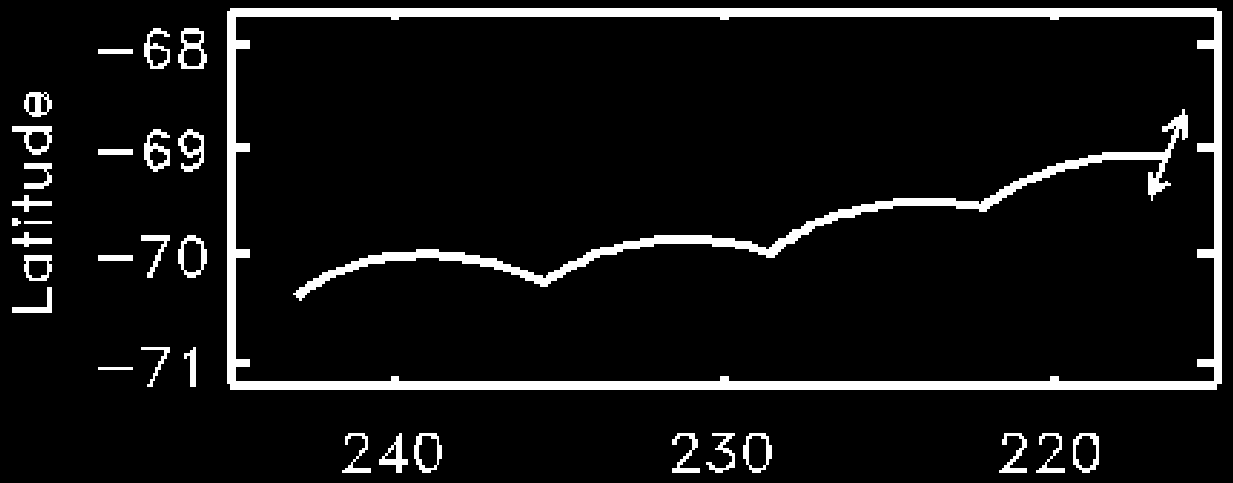
Stressing Europa II: Orbital Stress

NSR=0; M=000° after perijove



0.2 MPa

Cycloidal Ridges

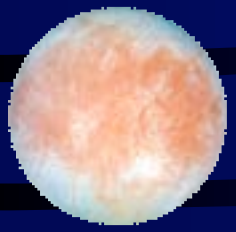


Hoppa et al. 99
LPL, Univ. of Arizona

Cycloids are explained by time-varying orbital stresses:

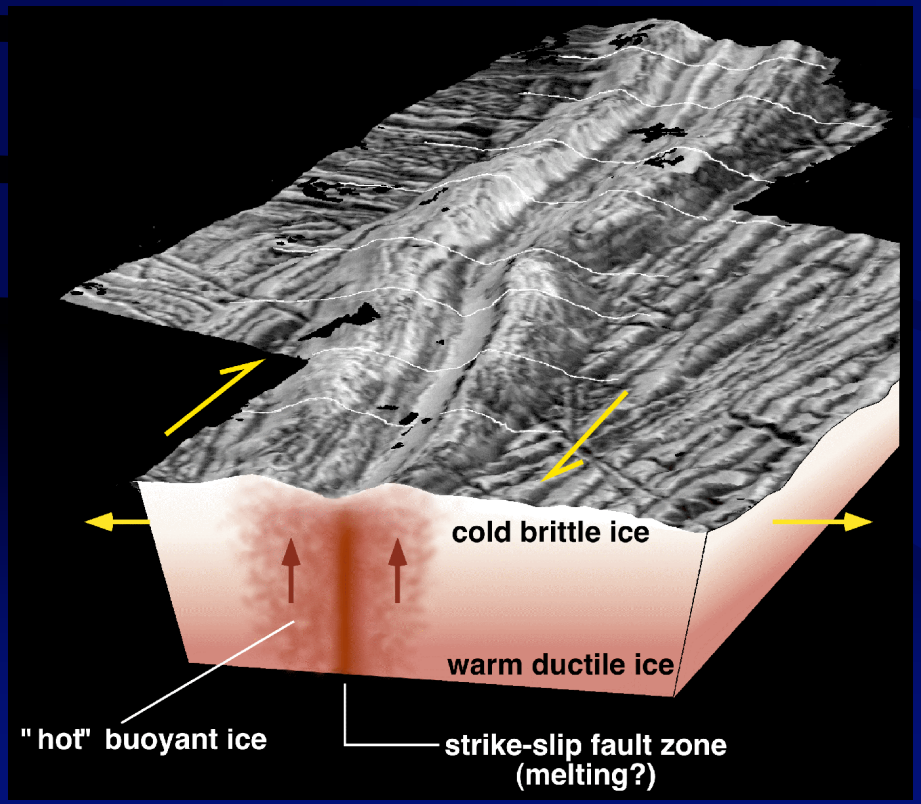
Ocean is necessary for sufficient tidal amplitude and stress!

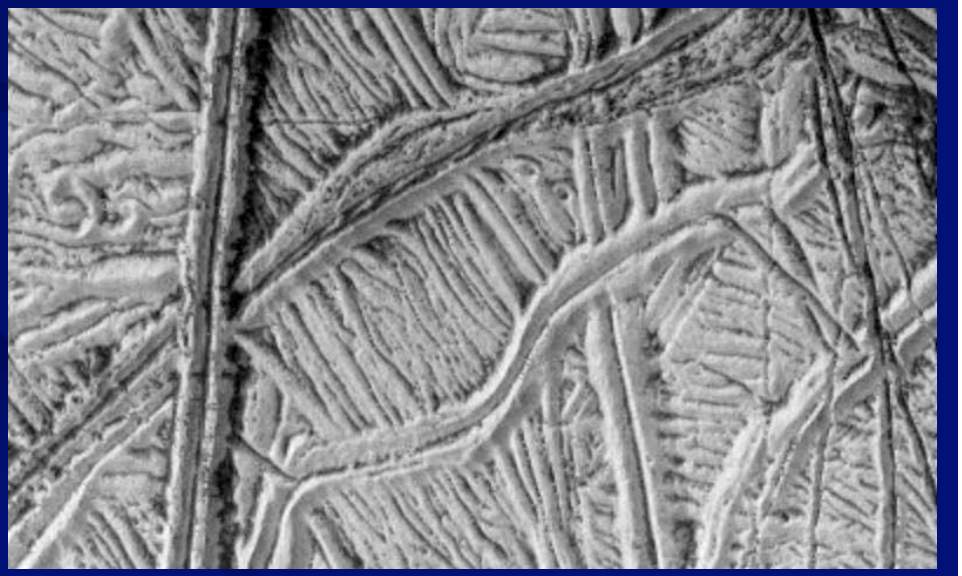

Ridges

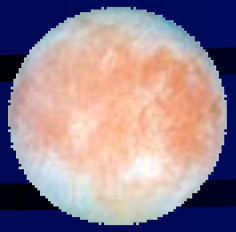


Europa's Geology: Ridges

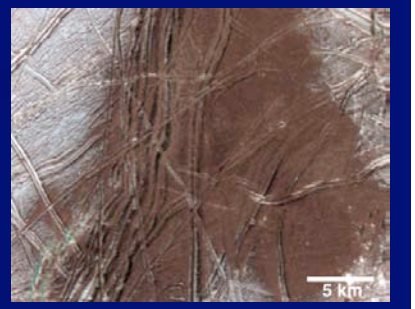
- Double ridges: extrusion or intrusion of water or warm ice?
- Shear heating along fracture plains may warm & melt ice.



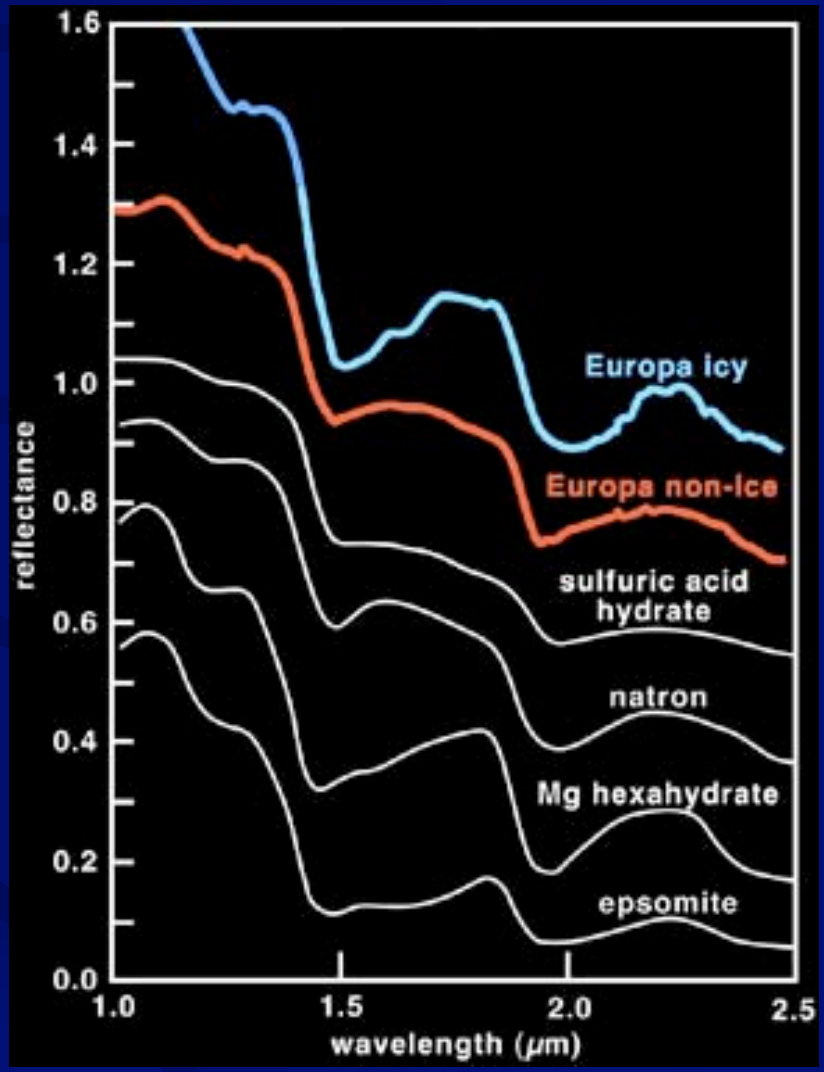




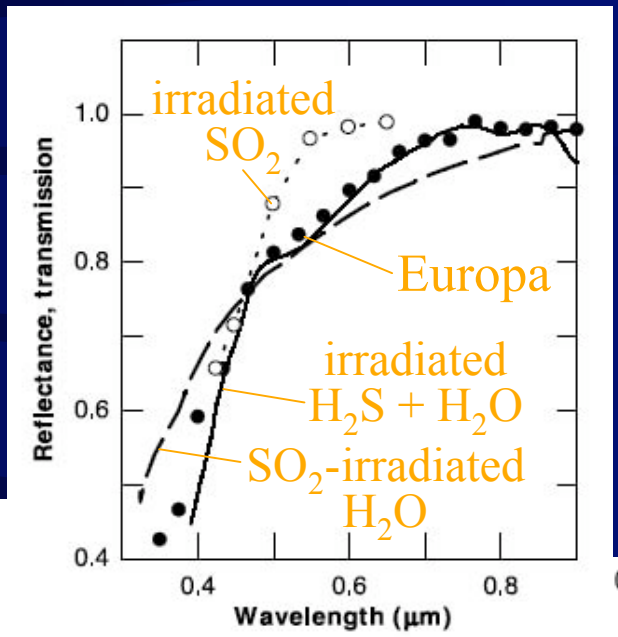
Surface Composition

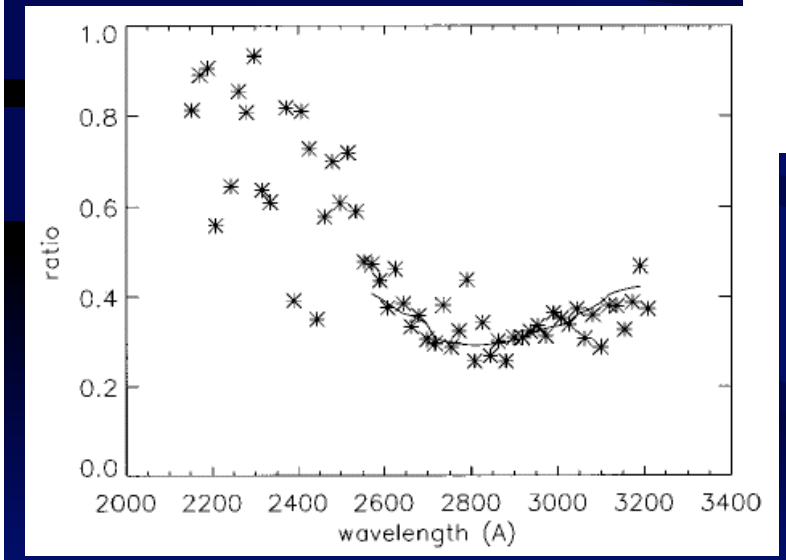


- "Non-ice" material shows shallow, asymmetrical IR absorptions.
- Candidate materials:
  - ✧ Hydrated sulfates salts (epsomite: $MgSO4 \cdot 7H_2O$).
  - ✧ Hydrated sulfuric acid ($H_2SO_4 \cdot nH_2O$).
  - ✧ Hydronium (H_3O) & H_2O_2.
- SO_2 inferred from UV.
- Sulfur chains may explain red visible color.



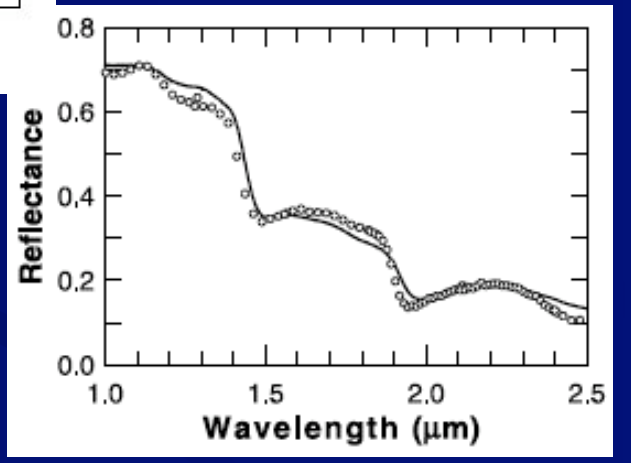
Proposed Radiolytic Sulfur Cycle





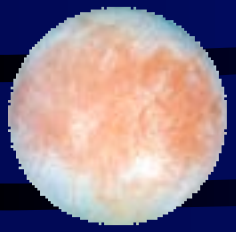
UV: SO_2

Visible: S_x



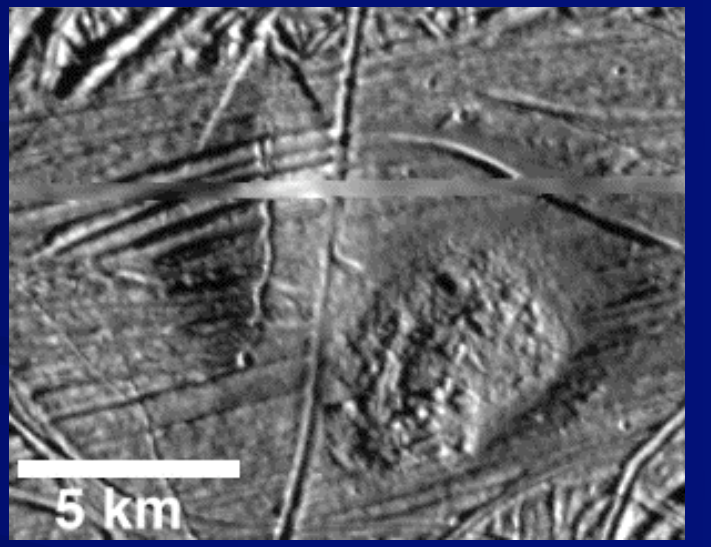
IR: $H_2SO_4 \cdot 8H_2O$

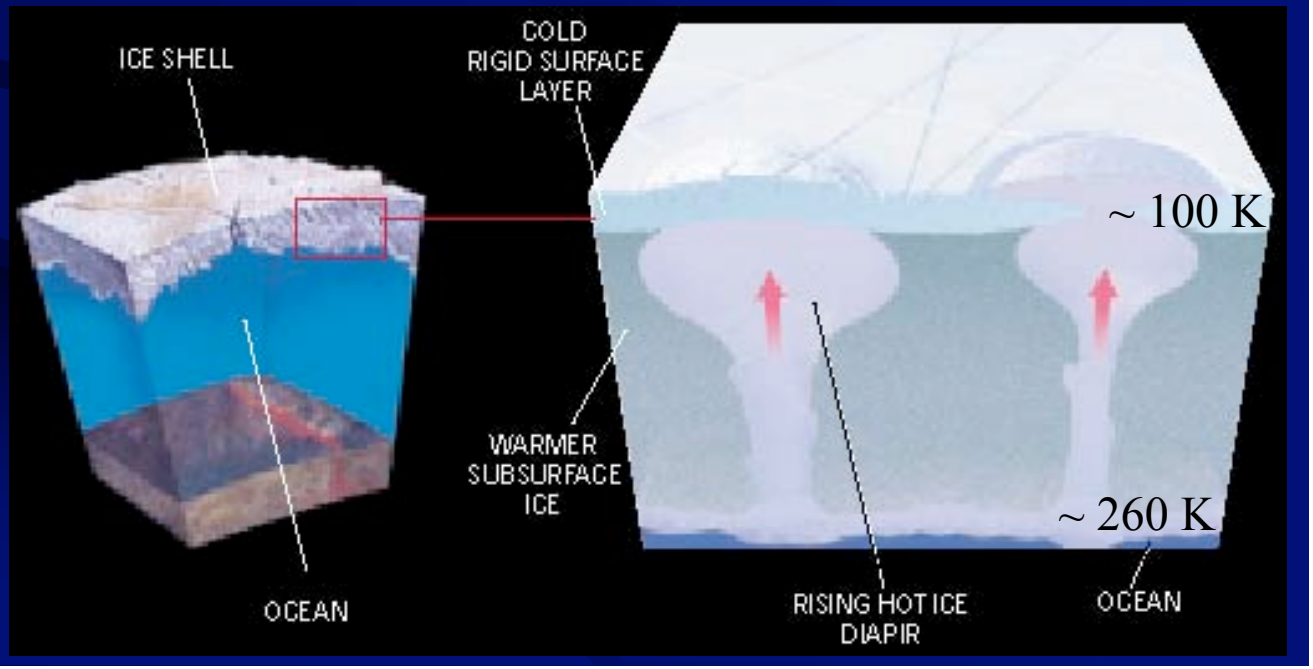
Carlson et al. [1999]



Convection in Europa's Ice Shell

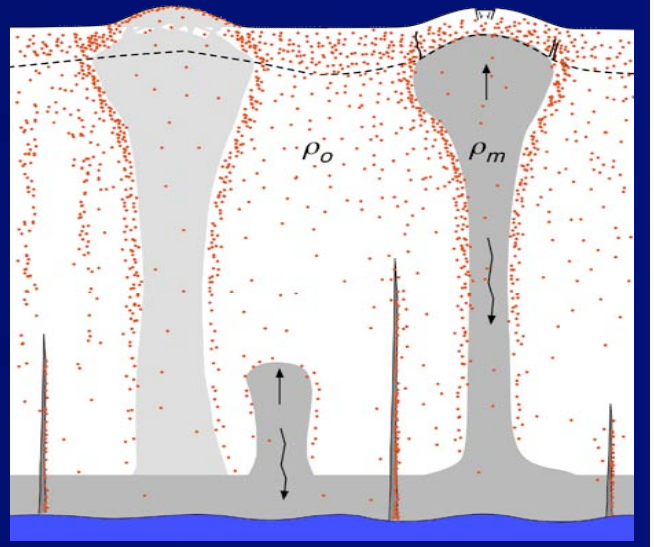
- Pits, spots, and domes suggest convection of ice shell.
- Tidal heating greatest in warm ductile ice near shell's base.
- Ice shell can convect if >20 km thick and tidally strained.



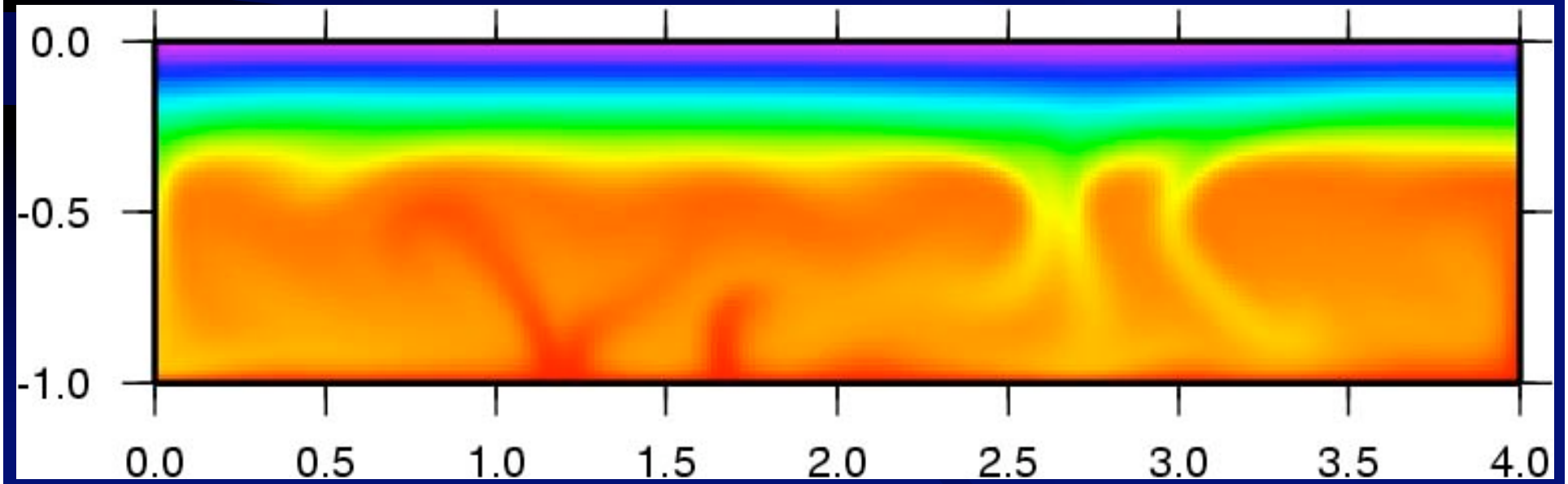


Convection in Europa's Ice Shell

- Circulation time scale ~10^5 yr.
- Thermal plumes cool as they rise.
- Segregation of low-eutectic impurities (chlorides or $H_2SO_4 \cdot nH_2O$) may allow plumes to breach "stagnant lid."

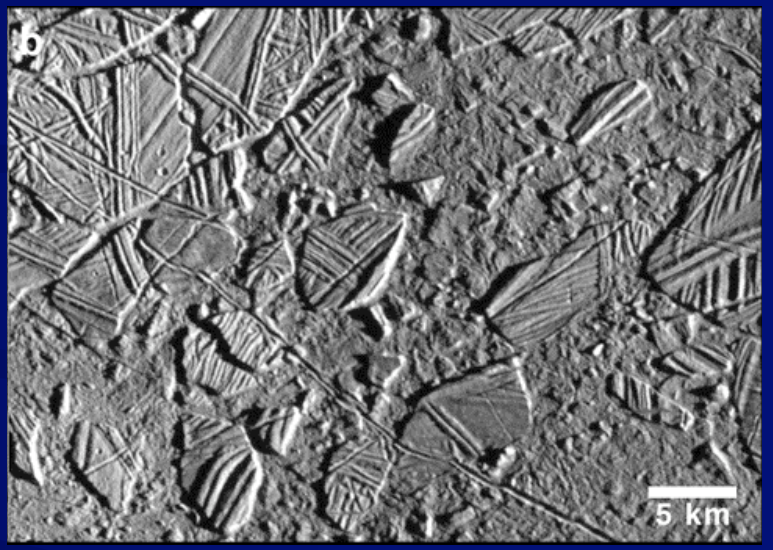


surface ≈ 100 K

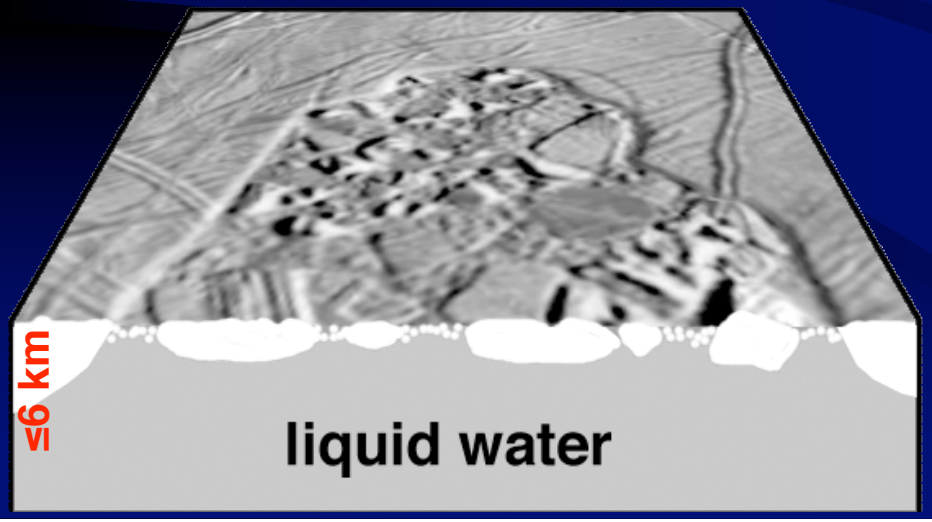


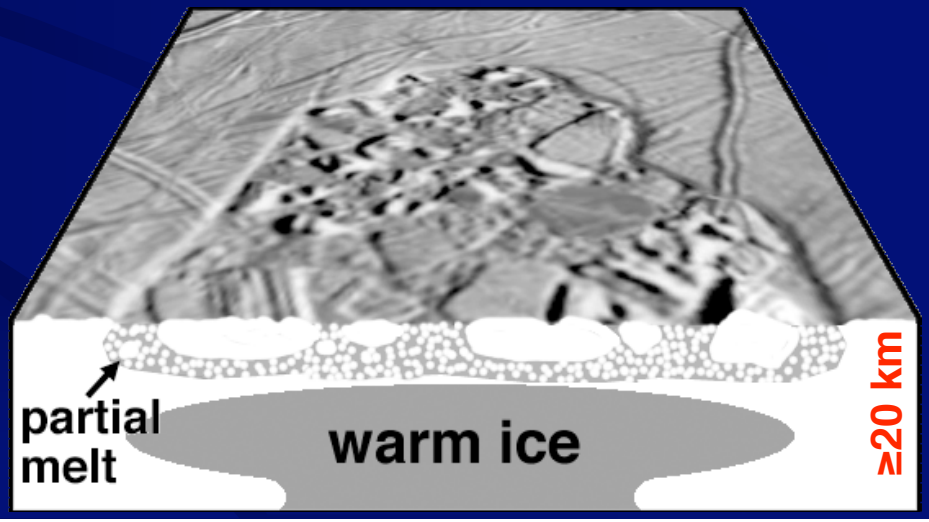
salty ocean ≈ 260 K

Chaos Models

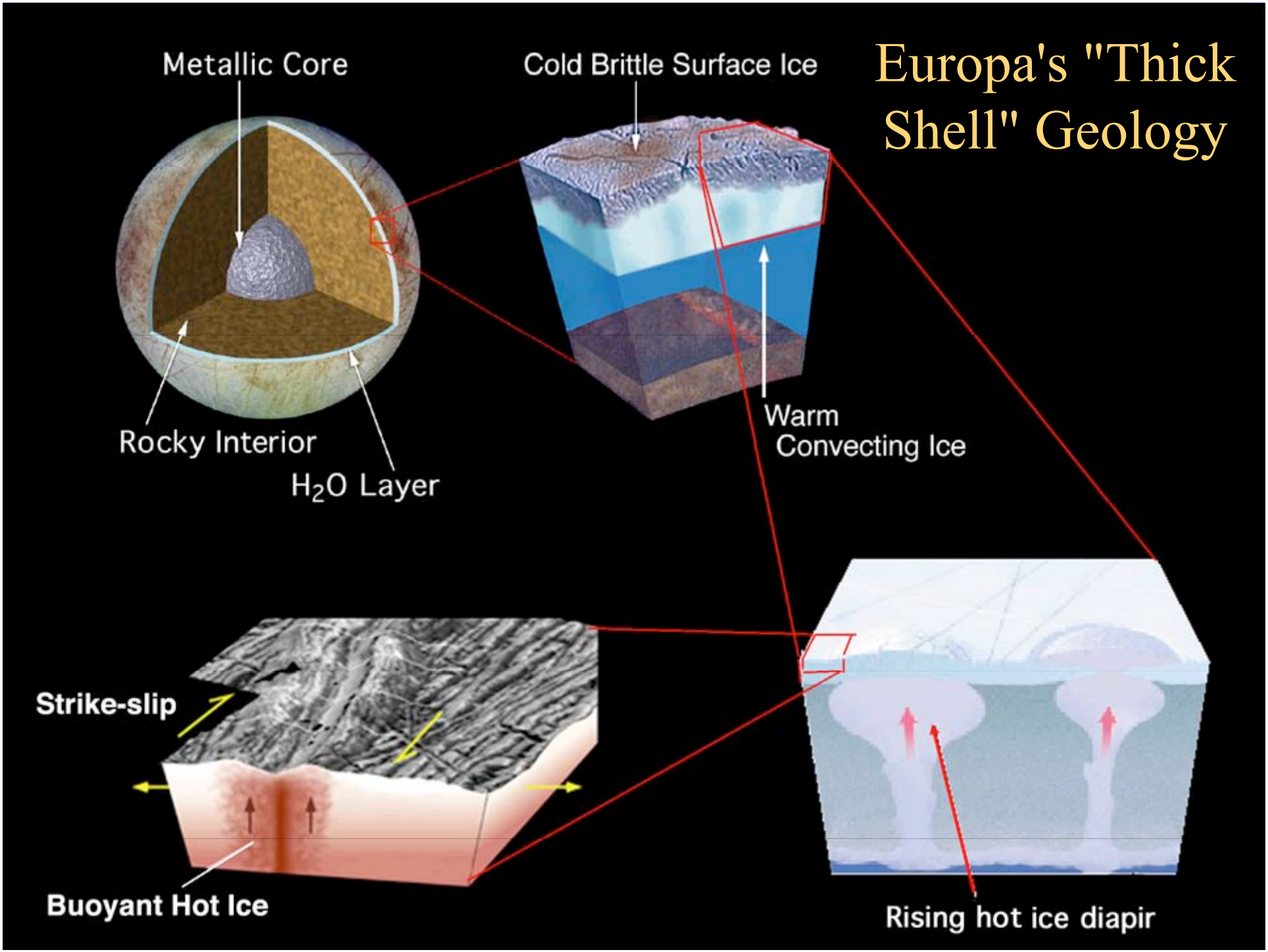


- Melt-through model:
  - ✧ Ice shell thins and melts above oceanic megaplumes.
  - ✧ But: requires huge heat flux, and ice flow may prevent thinning.
- Diapirism model:
  - ✧ Ice convection partially melts salty ice causing *in situ* degradation.
  - ✧ But plumes may cool too quickly to partially melt shallow ice.



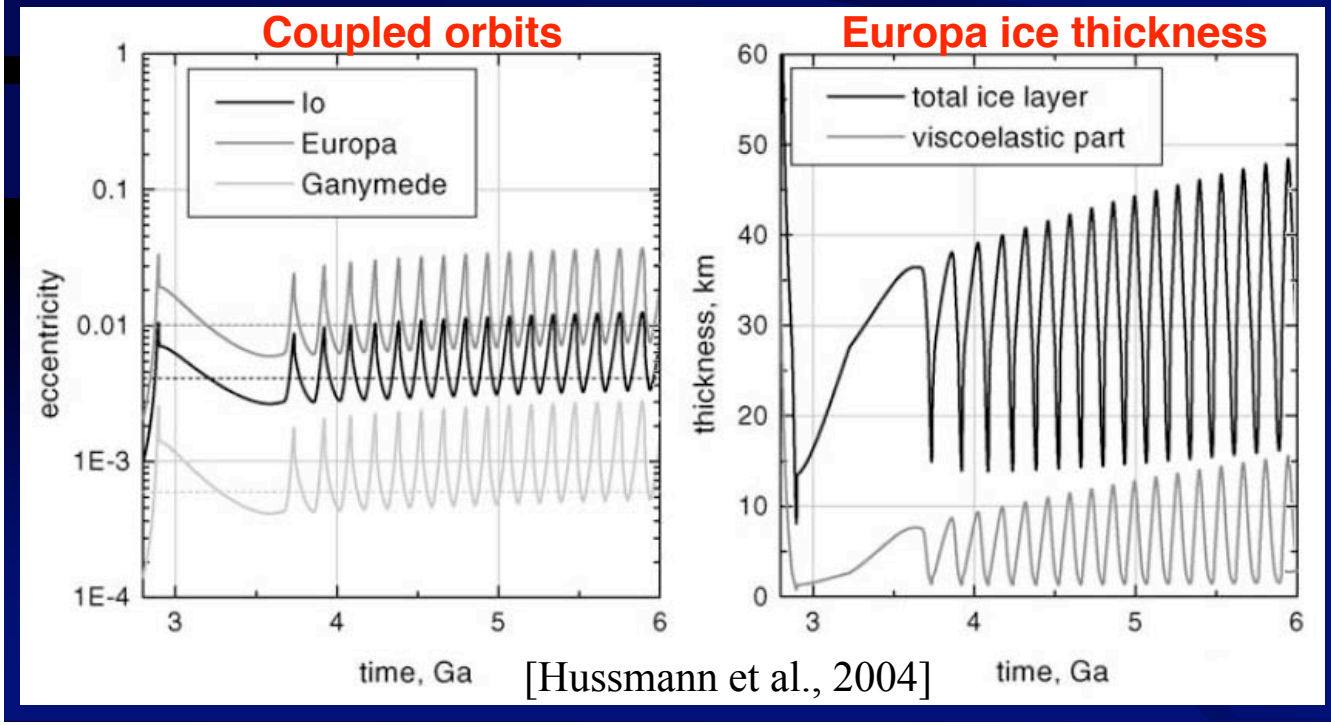


Journey to Conamara Chaos

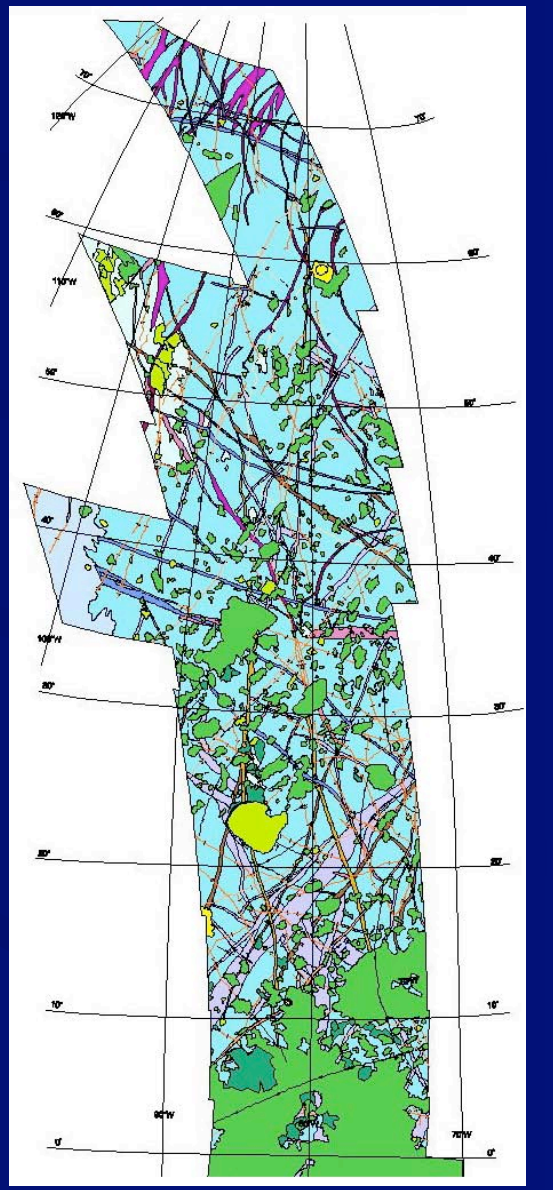

Europa's "Thick Shell" Geology
Metallic Core
Cold Brittle Surface Ice
Rocky Interior
H2O Layer
Warm Convecting Ice
Strike-slip
Buoyant Hot Ice
Rising hot ice diapir

Cyclical Geological Activity?

- Mapping suggests geological changes:
  - ✧ Transition from ridged plains to chaos; waning activity.
- Strange for a surface just ~50 Myr old.
- Tidal heating and orbital evolution of the 3 resonant Galilean satellites are linked:
  - ✧ Possible cyclical tidal heating & geological activity.



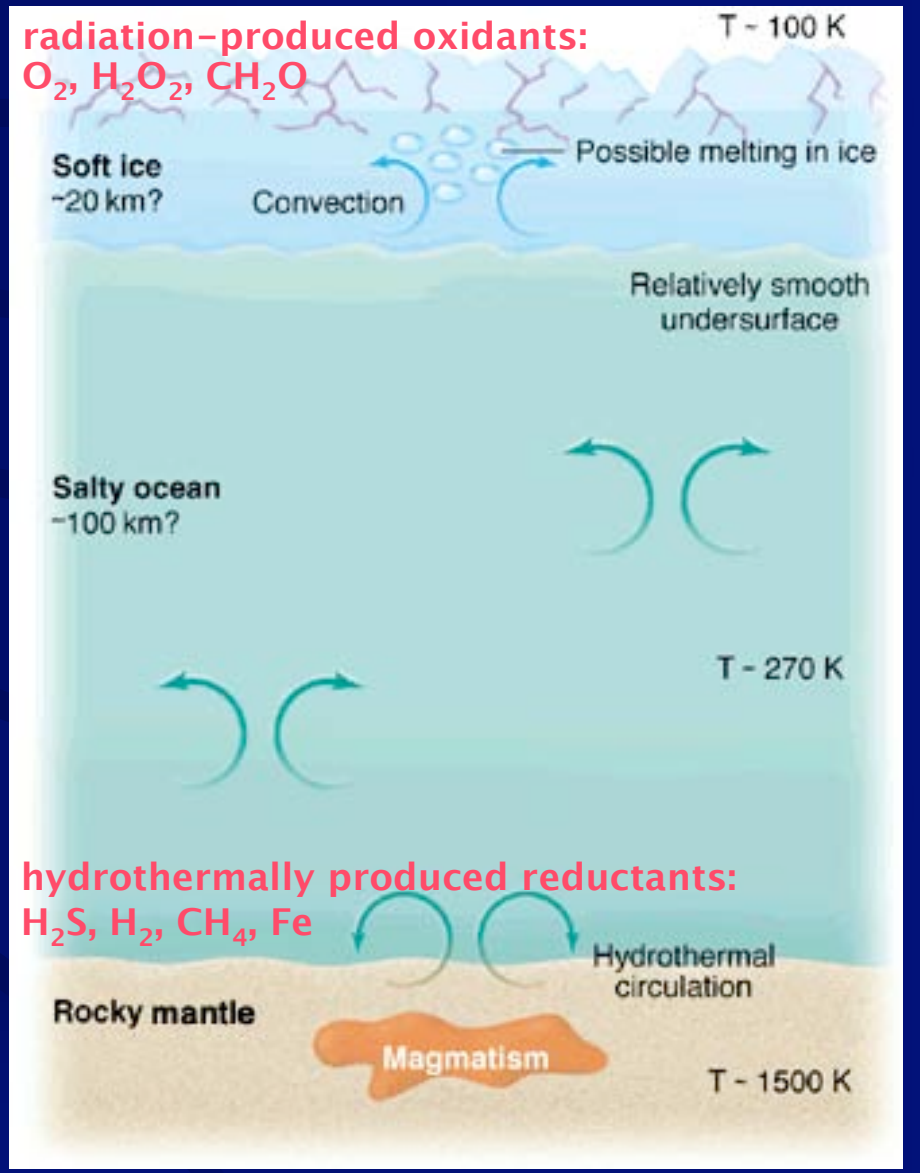
[Hussmann et al., 2004]



[Figueredo & Greeley, 2004]

Life in Europa's Hidden Ocean?

- Radiation destroys organics in upper ~10s cm of ice.
- Radiation of H_2O creates oxidants:
  - ✧ H_2O_2 (hydrogen peroxide) found.
  - ✧ HCHO (formaldehyde) predicted.
  - ✧ K^{40} decay ⇒ O_2, H_2.
- Sources of organic material:
  - ✧ CO_2 captured during accretion?
  - ✧ Organics from comet impacts: C≡N, C-H on Ganymede & Callisto.
- Hydrothermal activity at mantle?
- Better chance of life & detection if ocean & surface communicate.
- Activity may be non-steady-state.



Europa Geophysical Explorer

- Assess tidal effects to confirm the presence of a current global subsurface ocean.
- Characterize the properties of the ice shell and describe three-dimensional distribution of liquid water.
- Elucidate the formation of surface features and seek sites of current or recent activity.
- Identify and map surface composition with emphasis on compounds of astrobiological interest.
- Prepare for a future lander mission.