Europa: Processes and Habitability

Bob Pappalardo
Jet Propulsion Laboratory

Mosaic by Ted Stryk
Europa: Complex Geology

ridged plains

mottled terrain

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:
  - $\sim 80 - 170$ 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

Tension  Compression

0.2 MPa
Cycloidal Ridges

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 • 7H₂O).
  - Hydrated sulfuric acid (H₂SO₄ • nH₂O).
  - Hydronium (H₃O) & H₂O₂.
- SO₂ inferred from UV.
- Sulfur chains may explain red visible color.
Proposed Radiolytic Sulfur Cycle

Visible: $S_x$

UV: $SO_2$

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 $\sim 10^5$ yr.
- Thermal plumes cool as they rise.
- Segregation of low-eutectic impurities (chlorides or $\text{H}_2\text{SO}_4 \cdot n\text{H}_2\text{O}$) may allow plumes to breach “stagnant lid.”

surface $\approx 100$ K

salty ocean $\approx 260$ 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.

≤ 6 km ≥ 20 km

liquid water partial melt warm ice
Europa's "Thick Shell" Geology

- Metallic Core
- Cold Brittle Surface Ice
- Warm Convecting Ice
- Rocky Interior
- \( \text{H}_2\text{O} \) Layer
- 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.

[Figueredo & Greeley, 2004]

[Hussmann et al., 2004]
Life in Europa’s Hidden Ocean?

- Radiation destroys organics in upper ~10s cm of ice.
- Radiation of H$_2$O creates oxidants:
  - H$_2$O$_2$ (hydrogen peroxide) found.
  - HCHO (formaldehyde) predicted.
  - K$^{40}$ decay \(\Rightarrow\) 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.