Morphology and geochemistry of Europa: A comparative planetology view.

Surface layer of Europa: Implications for landing

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## Characteristics of Europa and the Earth’s Moon:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Europa</th>
<th>The Moon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean distance from the Sun, a.e</td>
<td>5.2</td>
<td>1</td>
</tr>
<tr>
<td>Mean distance from the planet, km</td>
<td>671,000</td>
<td>384,000</td>
</tr>
<tr>
<td>Orbital period, Earth’s days</td>
<td>3.55</td>
<td>27.3</td>
</tr>
<tr>
<td>Mean radius, km</td>
<td>1569</td>
<td>1738</td>
</tr>
<tr>
<td>Mean density, g/cm³</td>
<td>3.01</td>
<td>3.34</td>
</tr>
<tr>
<td>Escape velocity, km/s</td>
<td>2.02</td>
<td>2.38</td>
</tr>
<tr>
<td>Surface gravity, m/s²</td>
<td>1.31</td>
<td>1.62</td>
</tr>
<tr>
<td>Atmosphere pressure, bar</td>
<td>$10^{-11}$</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>Surface temperature, min, K</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>125</td>
</tr>
<tr>
<td>Surface material</td>
<td>H₂O ice</td>
<td>Silicate rocks</td>
</tr>
<tr>
<td>Mean surface age (Ma)</td>
<td>$10^7$</td>
<td>$4 \times 10^9$</td>
</tr>
</tbody>
</table>
Expected surface processes superposed on volcanic & tectonic “basement”

- Impact cratering and regardening
- Downslope movement of surface materials
- Radiation effects
Impact cratering and regardening

Impact fragmentation, ejection and ballistic deposition
  => Formation of fragmental regolith

Impact melting and vaporization (minor role)
  => Glueing together of fragments
  => Frost condensation on the surface and in pores
Europa,
Connamara Chaos
Galileo image
42 m per pixel
Cluster of secondary craters

The Moon,
Floor of crater Alphonsus
Ranger 9 image
50 m per pixel
Primary and secondary craters
Europa, Connamara Chaos
Galileo image
42 m per pixel
Cluster of secondary craters

The Moon, Floor of crater Alphonsus
Ranger 9 image
50 m per pixel
Primary and secondary craters
Europa, Connamara Chaos
9 m per pixel
Unfrequent craters

The Moon, Floor of Alphonsus
8.5 m per pixel
Numerous craters
The Moon, Floor of Alphonsus 8.5 m per pixel Numerous craters

Europa, Connamara Chaos 9 m per pixel Unfrequent craters
Equilibrium & nonequilibrium parts of impact crater population

Basilevsky, 1974:
On the Moon
median thickness
of regolith:
\[ H_{\text{med}} \approx \frac{D_{\text{crit}}}{25} \]

This work:
On Europa, where
majority of craters
seems to be
secondary and
thus more shallow,
median thickness
of regolith should
be smaller
\[ H_{\text{med}} \approx \frac{D_{\text{crit}}}{50} \]

Shoemaker, 1971; Florensky et al., 1972

\[ N_{\text{equil}} = 10^{10.9} \cdot D^{-2} \]

\[ N_{\text{nonequil}} \sim D^{-3} \]
Impact crater frequencies on Europa

Zahnle et al., 2008
Impact crater densities on Europa and the Moon

\[ D = 10^{0.9 \cdot D^2} \]

- Europa, Extrapolation
- Luna 16 / Lunokhod 1
- Observed
- Primaries
Estimates of regolith thickness:

<table>
<thead>
<tr>
<th>Luna 16 / Lunokhod 1</th>
<th>Europa</th>
</tr>
</thead>
<tbody>
<tr>
<td>D crit ≈ 100 m</td>
<td>D crit ≈ 30 m</td>
</tr>
<tr>
<td>H med ≈ D crit / 25</td>
<td>H med ≈ D crit / 50</td>
</tr>
<tr>
<td>=&gt; ~ 4 m</td>
<td>=&gt; ~ 0.5 m</td>
</tr>
</tbody>
</table>

Cooper et al. (2001) => ~ 1 m

On Europa, within the clusters of secondaries, thickness of impact-formed regolith is probably much larger than H med, while far from the clusters and in the areas of recent endogenic resurfacing such regolith should be much thinner or even absent.
On Europa: Coarse-grained fragmental ice regolith, possibly with some frost on top and

On the Moon: Fine-grained fragments + agglutinates
Downslope movement of surface materials:

On Europa a downslope surface material movement is expected and observed in the areas with rough surface topography:

Chaoses, Rugged terrain, Faults, Domes, Impact craters

It should be provoked by day-night temperature change and meteorite impacts
Downslope material movement on Europa and terrestrial and lunar analogs

- Taluses on Europa
- The landslide at the Apollo 17 site
- Earth, Talus cone
- The Moon, Landslide at the Apollo 17 site
Radiation environment at Europa orbit

**DIVINE + GIRE JOVIAN RADIATION MODELS**

Contour plots of >1 MeV electron and >10 MeV proton integral fluxes at Jupiter. Coordinate system used is jovi-centric. Models are based on Divine/GIRE models. Meridian is for System III 110° W.

From: Henry B. Harrett, JPL / OPFM Instrument Workshop / June 3-5, 2008
Radiation by particles on Europa is very surficial

Radiation Environment at Europa’s Surface

Flux spectra from EPD measurements at Europa during E4 encounter (Cooper et al., 2001). Electron spectra from EPD at 20-700 keV and from Divine and Garrett (1983).

Dose rate (rad(H$_2$O)/s) vs depth curves for, electrons, protons, oxygen, and sulfur at apex of Europa’s trailing hemisphere.

Dose of protons falls by 6 orders of magnitude at 1 cm depth
Radiation effects on Europa:

Most charged particles preferentially impact trailing hemisphere, except $> 25$ MeV electrons, which preferentially impact the leading hemisphere.

Radiolysis:

$\Rightarrow$ Major reaction $2 \text{H}_2\text{O} \rightarrow \text{H}_2\text{O}_2 + \text{H}_2$

(Spinks and Wood, 1990)

Sputtering:

$\Rightarrow 6 \times 10^4$ years to erode 1 mm of ice

Compare: Impact burial $\Rightarrow 10^3$ years per mm of ice

so impacts are much more effective than sputtering

(Cooper, 2001)

Radiation Damage:

$\Rightarrow$ Defects in ice $\Rightarrow$ Thin ($<1$ mm) amorphous layer

(Hansen and McCord, 2004).
Conclusions:

- Surface layer of Europa is expected to be mostly an impact-produced regolith with decimeter-scale median thickness. In some areas it may be much thicker, while in others – thinner or almost absent.

- It consists probably of relatively coarse-fragments of water ice (ice breccia) partially lithified due to contact welding and frost deposition in the pores.

- On top of fragmental regolith a water frost may present.

- Within the topographically rough areas and landforms a downslope material movement may occur.

- Radiation effects (radiolysis, sputtering, radiation damage) affect mostly the uppermost mm-cm layer.
Thanks to A.V. Ivanov, B.A. Ivanov, M.A. Ivanov, R. Kuzmin and V.I. Shematovich for help.

Thank you for your attention!

www.xtywebworks.ns.ca/week37.html