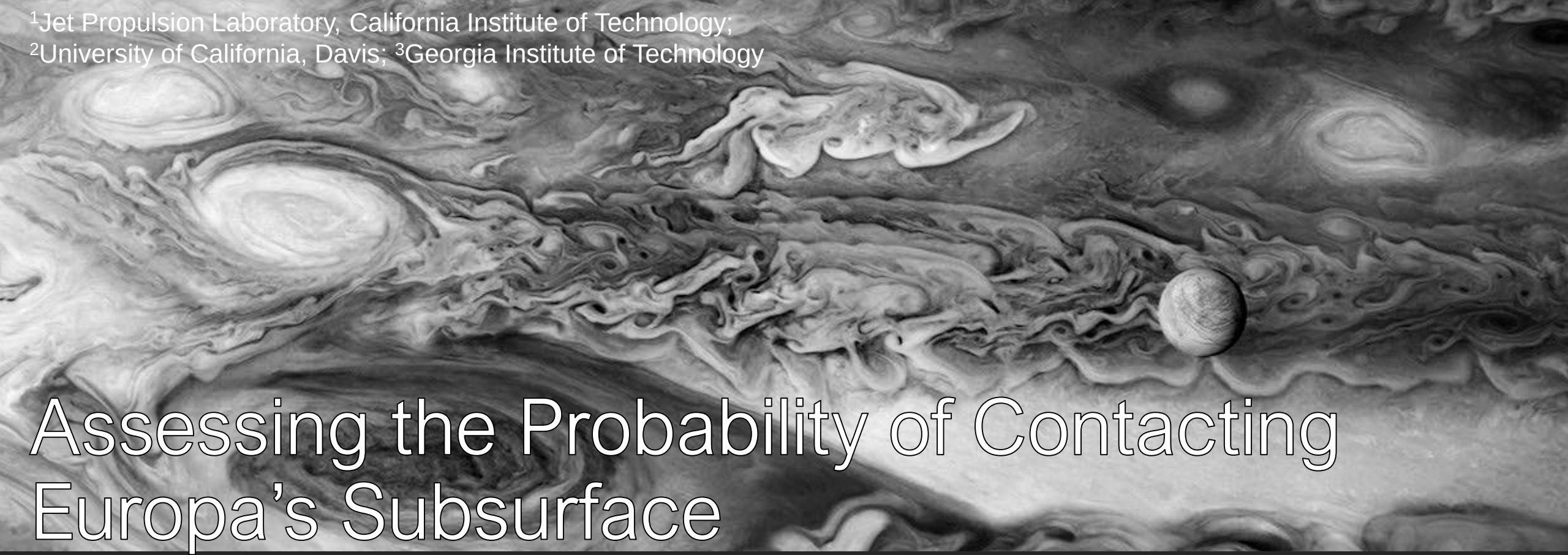
[1]Jet Propulsion Laboratory, California Institute of Technology;
[2]University of California, Davis; [3]Georgia Institute of Technology



Assessing the Probability of Contacting Europa's Subsurface

An Approach to Planetary Protection for Geologically Active Ocean Worlds

Presenter: Michael DiNicola[1]

Co-authors: Samuel Howell[1], Kelli McCoy[1], Zaki Hasnain[1], Samuel Fleischer[2], Hayden Burgoyne[1], Britney Schmidt[3] and Chet Everline (retired)[1]

Jet Propulsion Laboratory, California Institute of Technology

EUROPA CLIPPER

Background

NASA Requirement (NPR 8020.12D): The probability of inadvertent contamination of an ocean or other liquid water body shall be less than 1×10^{-4} per mission.

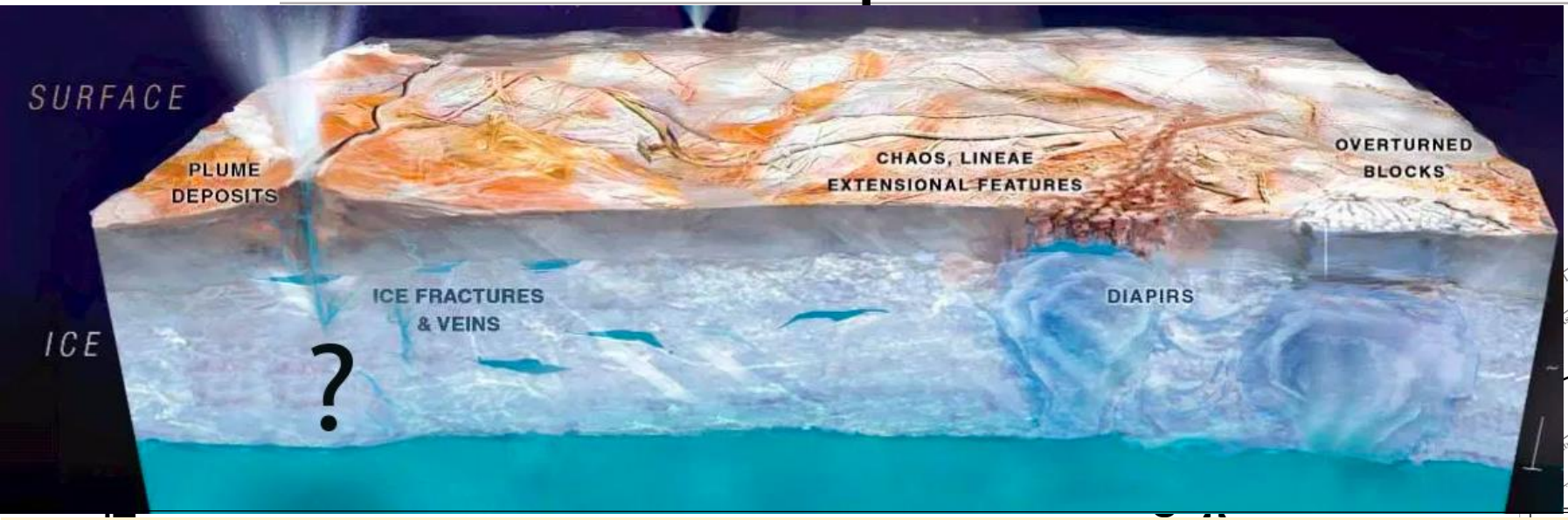
The calculation of this probability shall **include a conservative estimate of poorly known parameters**, and address the following factors, at a minimum:

- ✓ Bioburden at launch
- ✓ Cruise survival for contaminating organisms
- ✓ Organism survival in the radiation environment adjacent to the target
- ✓ Probability of encountering/landing on the target, including spacecraft reliability
- ✓ Probability of surviving landing/impact on the target
- ✓ **Mechanisms and timescales of transport to the subsurface**
- ✓ Organism survival and proliferation before subsurface transfer
- ✓ *Organism survival and proliferation during, and after subsurface transfer (prob=1)*

November, 2018 Workshop held by PPO and panel of experts in biology, math, PP and planetary science

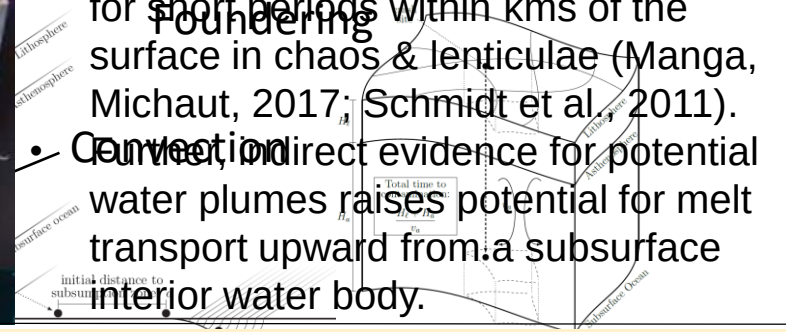
- ➢ Approved Clipper model and approach
- ➢ PPO agreed to **limit period of concern for the requirement to 1,000 years** (until the year 3000).

Explored Mechanisms and Timescales of Transport to Subsurface



BUT:

- The thickness of Europa's ice shell is poorly constrained, few-50 km thick (Billings and Kattenhorn, 2005).
- Perched water lakes may be present for short periods within kms of the surface in chaos & lenticulae (Manga, Michaut, 2017; Schmidt et al., 2011).
- Further, indirect evidence for potential water plumes raises potential for melt transport upward from a subsurface interior water body.



Mechanisms of transport were explored, but lack of knowledge of interstitial water led us to limit the model to the notion of ***Resurfacing***

- Cannot adequately model when interstitial water will be contacted, so conservatively assume any geologic transport of terrestrial microorganisms beneath the surface instantly contaminates an interior water body.
- Clipper did not need timescales through subsurface to satisfy the PP requirement.

Resurfacing: Any process that replaces an area on the surface of Europa that could initiate subsurface transfer.

- Each geologic resurfacing process contributes to an *average* exposed surface age of ~65 Myr (Min-Max: 20-270Myr), based on estimates from crater size frequency distributions (Bierhaus et al., 2009; Zahnle et al., 1998).

Resurfacing Model Link with Geology

Geology

Poorly constrained ice shell thickness, possible melt transport, and potential near-surface lakes (Billings and Kattenhorn, 2005)

Geologic ice-shell transport mechanisms are highly debated (multiple references)

Historical geological resurfacing are not a reliable indicator of present or future geologic modification (Leonard et al. 2017)

20 Myr–270 Myr average age (Bierhaus et al. 2009), from summed effect of all resurfacing processes. Best est: 65 Myrs

Resurfacing on Europa is unlikely to produce an average surface age <20 Myr over timescales << 20 Myr

Brittle thickness is predicted to be no thinner than ~1 km (Billings and Kattenhorn, 2005 & ref's therein).

Structures that penetrate a brittle layer should have lengths ≥ brittle thickness (Cowie and Scholz 1992; Dugdale 1960).

Geologic features vary in time & space, and are not a perfect indicator of present or future activity in that region (Leonard et al. 2017)

Mathematical Modeling

Resurfacing of a single region of Europa containing a viable microorganism delivered by Clipper will bring it into contact with the subsurface and, potentially, liquid water

All areas of Europa assumed to be geologically active

Model resurfacing of each grid element of Europa as a Poisson Process, with a resurfacing rate calibrated to maintain the observed average surface age of 65 Myrs (min - max: 20 Myrs - 270 Myrs)

Resurfacing rate is time-independent (constant)

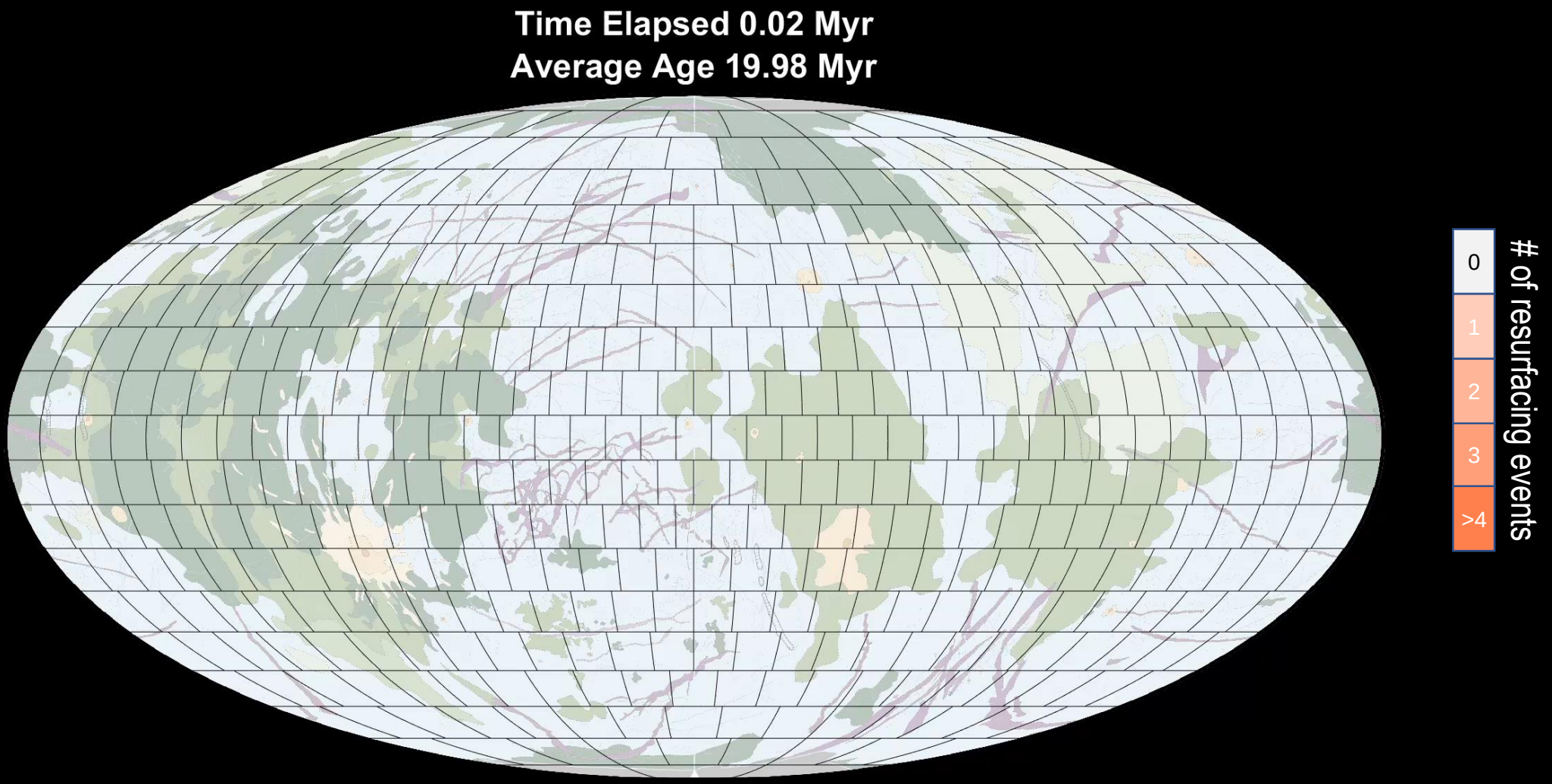
Resurfacing rate = 1 / Observed Surface Age

Partition Europa into a grid of equal area pieces, no less than 1 km^2 in size, to model resurfacing (conservative)

Assume each grid element resurfaces at the same average rate

Grid elements resurface independently of one another

Monte Carlo Illustration of the Resurfacing Model



While the model allows multiple resurfacing events to occur over time, the Planetary Protection model is concerned with the first time a grid element resurfaces with a Clipper-delivered microorganism

[Map: Leonard et al., 2017]

Model Uses an Analytic Solution

Probability that an area of the Europa surface hosting a microorganism resurfaces within *t* years given impact / contact occurs (for Clipper, *n* denotes the maneuver that was failed that resulted in impact).

impact / conta
determined by E
surface ice porc
spacecraft orier
impact / contact

$A_{m,n,q}$ IS A VERY IMPORTANT PARAMETER. **Hayden Burgoyne** is presenting how to calculate this in **"Cratering and Debris Scatter after Inadvertent Impact of Europa Clipper onto an Icy Body"** at **3:15 pm today** at the **Hyatt Regency Bellevue – Auditorium.** DON'T MISS IT!!

$$\Pr\left(R_t \middle| I_n\right) = \frac{1}{M_n} \sum_{m=1}^{M_n} \sum_{q=1}^{Q_{n,m}} w_q \left[1 - e^{-\lambda t A_{m,n,q}}\right]$$

Maximum # of grid elements of the Europa surface with a microorganism delivered by the spacecraft

# of trajectories impacting / contacting Europa

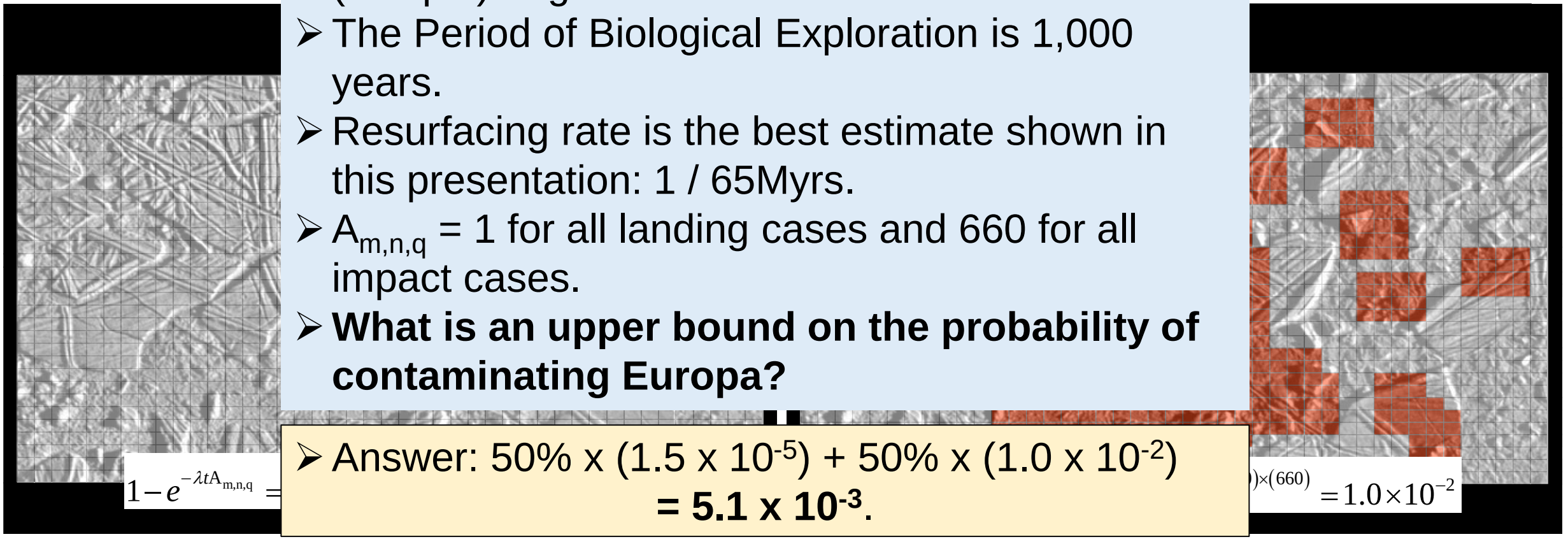
Weighting factor for each porosity / orientation pair

Probability that some Europa grid element with a microorganism delivered by the spacecraft resurfaces within *t* years when

- Impact / contact of Europa occurs on trajectory *m*
- Ice porosity of the Europa surface and impact orientation of the spacecraft are according to case *q*

How can this be Applied to your Mission?

- Suppose your mission either lands precisely on Europa with 50% chance or impacts at a shallow (oblique) angle with 50% chance.
- The Period of Biological Exploration is 1,000 years.
- Resurfacing rate is the best estimate shown in this presentation: 1 / 65Myrs.
- $A_{m,n,q}$ = 1 for all landing cases and 660 for all impact cases.
- **What is an upper bound on the probability of contaminating Europa?**



- Answer: 50% x (1.5×10^{-5}) + 50% x (1.0×10^{-2}) **= 5.1×10^{-3}.**

Soft Landing or Non-oblique Impact, $A_{m,n,q}$ = 1
$Pr(R_t \mid I_n) = 1.5 \times 10^{-5}$

Oblique Impact, $A_{m,n,q}$ = 660
$Pr(R_t \mid I_n) = 1.0 \times 10^{-2}$

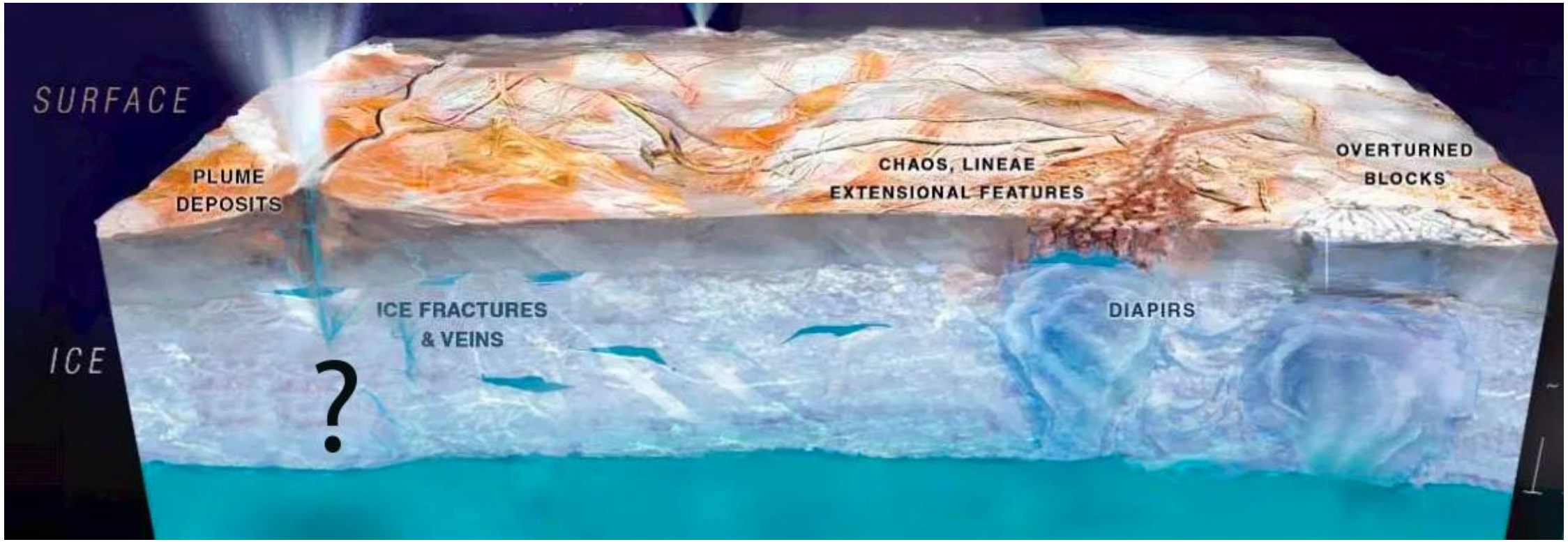
Summary

- Mechanisms of transport were explored, but lack of knowledge of interstitial water led us to limit the model to the notion of *Resurfacing.*
- *Resurfacing*: Any process that replaces an area on the surface of Europa that could initiate subsurface transfer.
- Range for the resurfacing rate:
  - Worst Case: 1 / 20 Myrs
  - CBE Case: 1 / 65 Myrs
  - Best Case: 1 / 270 Myrs
- The max number of grid elements hosting a microorganism delivered by the S/C, $A_{m,n,q}$, needs to be estimated through cratering and debris analysis.
  - See the presentation by Hayden Burgoyne at 3:15 pm today!
- Shallow angle (oblique) impacts can be a driver of the probability of contamination.
- Approach and model approved at the Clipper 2018 Workshop by the PPO and workshop panel.
  - Period of biological exploration set to 1,000 years.

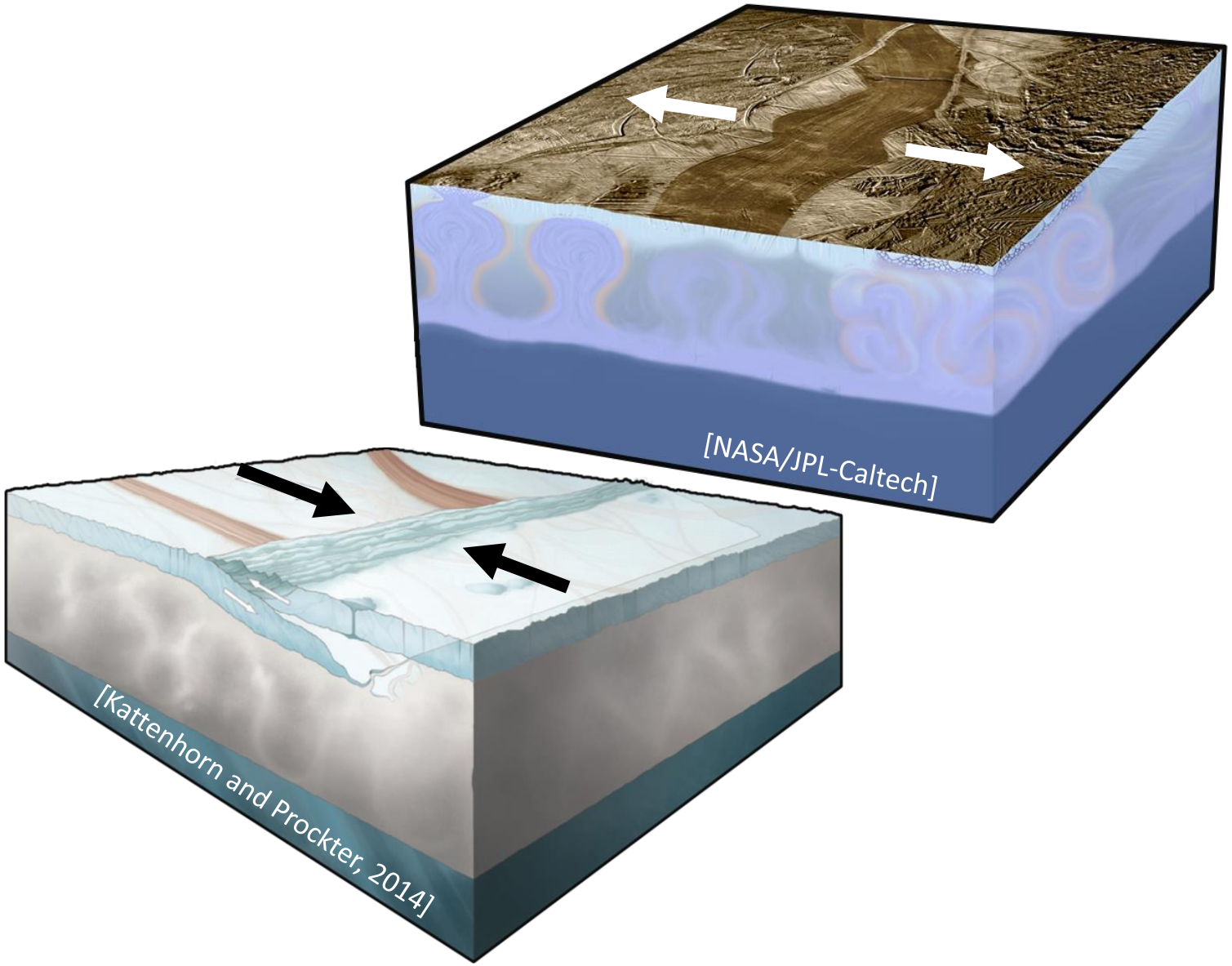
Backup

Current State of Knowledge: Europa Geology/Geophysics (1/6)

- **Because melt bodies may be near the surface (1s km), and because the ice shell thickness is unknown, we assume that any resurfacing results in water body contamination**



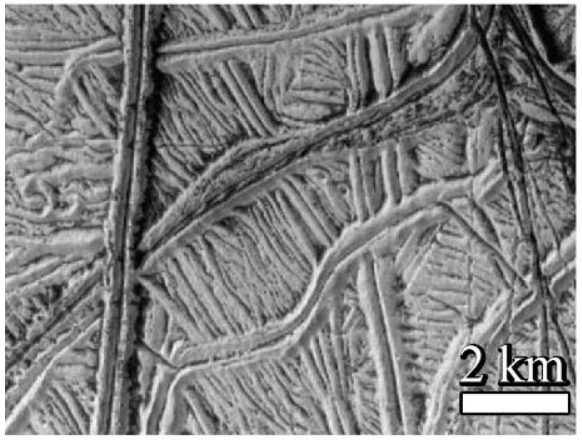
Current State of Knowledge: Europa Geology/Geophysics (2/6)



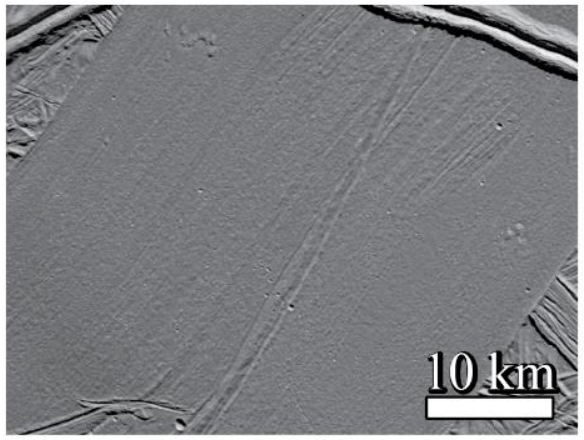
- **Because melt bodies may be near the surface (1s km), and because the ice shell thickness is unknown, we assume that any resurfacing results in water body contamination**
- Different mechanisms have different resurfacing length and time scales. **The effect is an average age >20 Myr.**

Current State of Knowledge: Europa Geology/Geophysics (3/6)

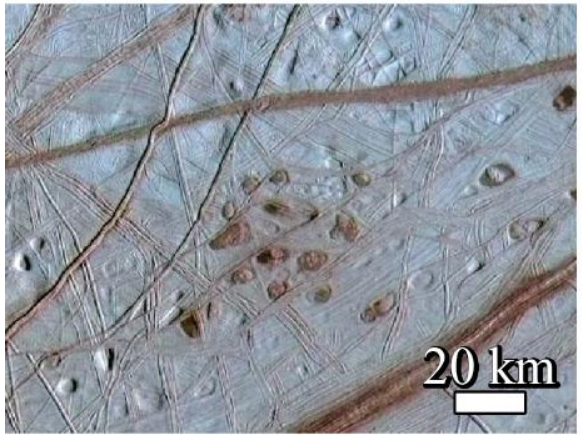
Ridges



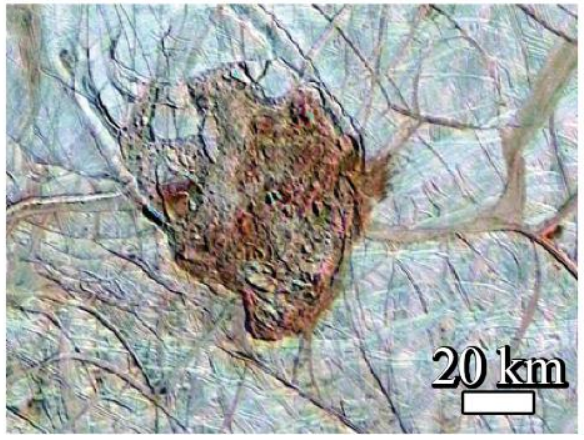
Bands



Lenticulae



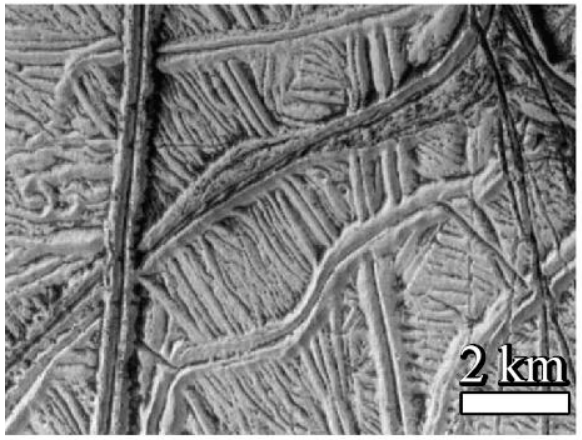
Chaos



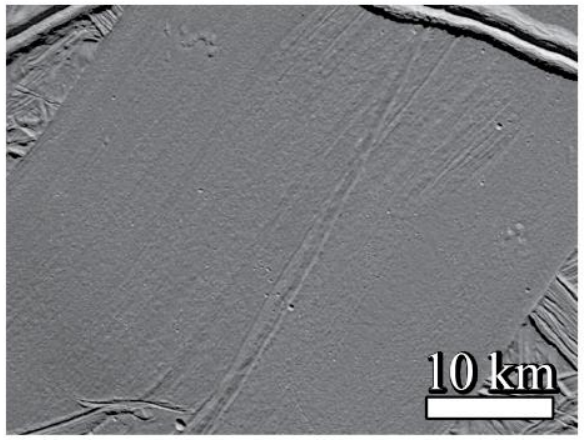
- **Because melt bodies may be near the surface (1s km), and because the ice shell thickness is unknown, we assume that any resurfacing results in water body contamination**
- Different mechanisms have different resurfacing length and time scales. **The effect is an average age >20 Myr.**
- Past geology is not necessarily predictive of present or future activity (and incomplete mapping)
- **Thus, we conservatively assume that resurfacing is equally likely anywhere, regardless of geologic history in that region**

Current State of Knowledge: Europa Geology/Geophysics (4/6)

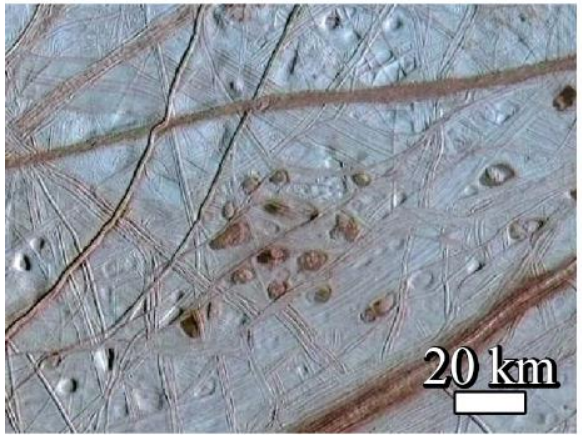
Ridges



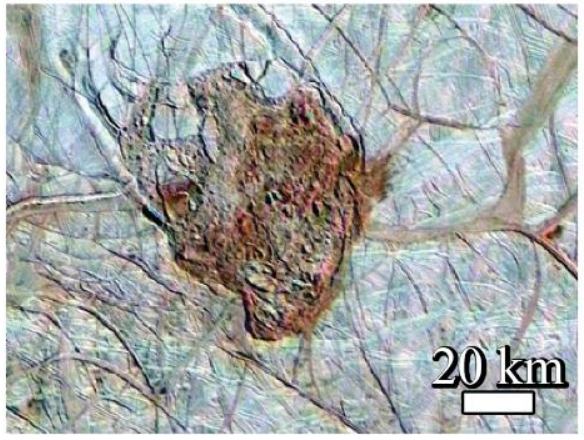
Bands



Lenticulae

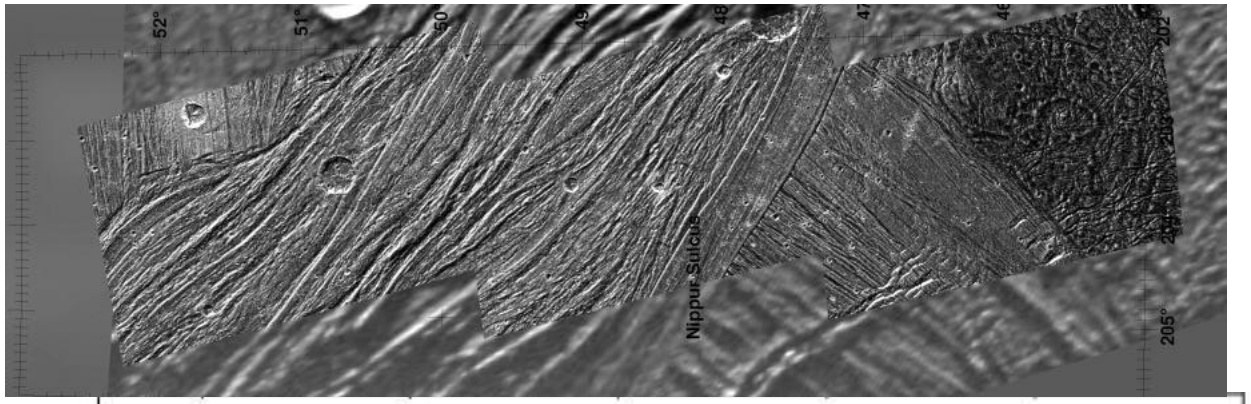


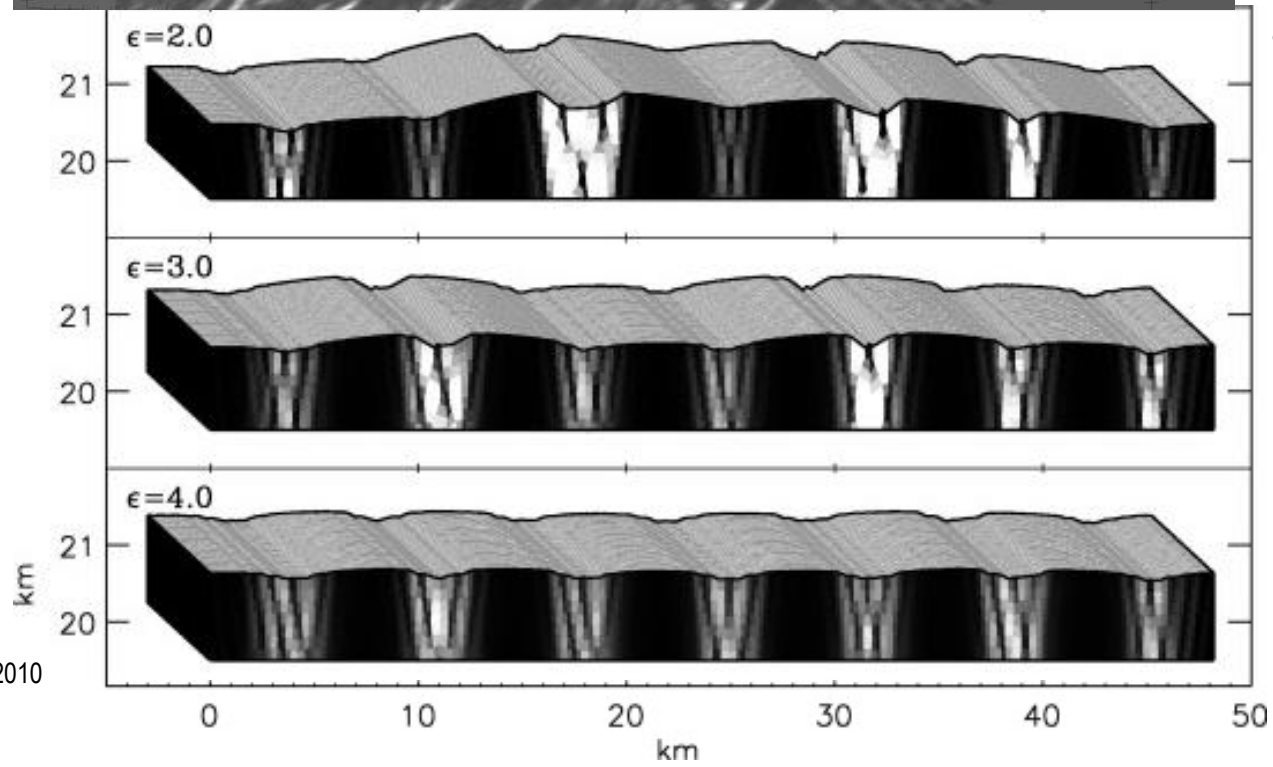
Chaos



- The average surface age approaches $1/\lambda$ over time scales a few times greater than $1/\lambda$
- **We conservatively assume the average surface age is no less than $1/\lambda$ = 20 Myr (λ = 1/20 Myr) through recent geologic history and for similar timescales after impact**

Current State of Knowledge: Europa Geology/Geophysics (5/6)

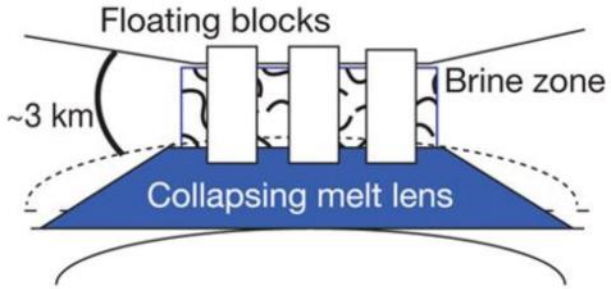


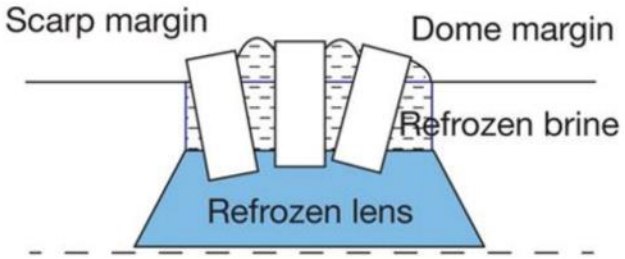


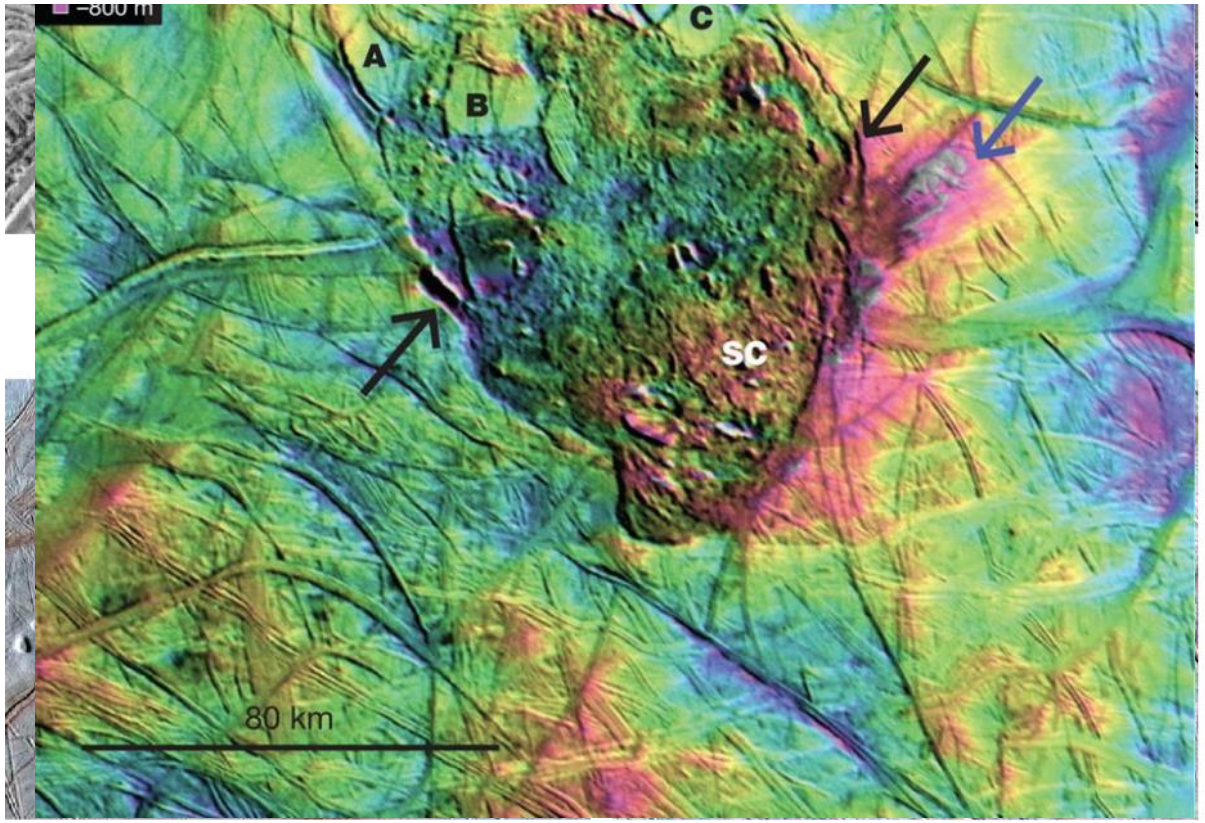
Bland et al. 2010

- The average surface age approaches $1/\lambda$ over time scales a few times greater than $1/\lambda$
- **We conservatively assume the average surface age is no less than $1/\lambda$ = 20 Myr (λ = 1/20 Myr) through recent geologic history and for similar timescales after impact**
- Tectonic (fault, crack) structures allowing resurfacing should have length scales greater than the brittle thickness (no less than 1 km)

Current State of Knowledge: Europa Geology/Geophysics (6/6)







Schmidt et al. 2011

- The average surface age approaches $1/\lambda$ over time scales a few times greater than $1/\lambda$
- **We conservatively assume the average surface age is no less than $1/\lambda$ = 20 Myr (λ = 1/20 Myr) through recent geologic history and for similar timescales after impact**
- Tectonic (fault, crack) structures allowing resurfacing should have length scales greater than the brittle thickness (no less than 1 km)
- Structures associated with melting should have spatial scales equivalent to the depth of the water body (observed to be >2km for Thera Macula)
- **We conservatively assume spatial dimensions of resurfacing may be as small as 1 km^2**