Europa Regional-Scale Geology, Stratigraphy, and Implications for Future Landers

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Outline

- Introduction
- Characteristics of ideal landing sites
- Tectonic features – lateral tectonics
- Cryomagmatic features – vertical tectonics
- Impact features
- Overall assessment of best landing sites
  - Type example: Castalia Macula

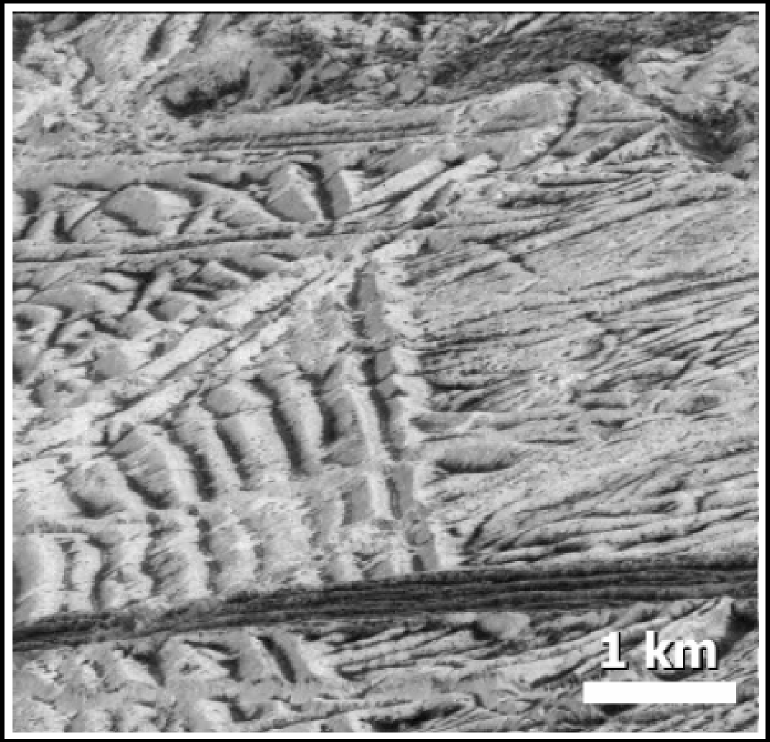
Considerations for Europa Landing sites

Europa's surface is young, ~60 Ma

- Some parts of Europa are extremely young, e.g., Pwyll is <5 Ma.
- Models of tidal stress enable us to predict most promising locations of current surface activity

Ideal surface sampling site will be:

1. A place where the subsurface (ideally the ocean) has communicated with the surface
2. Relatively young/unaltered by radiation processing, impact bombardment, etc.
3. Relatively flat and/or smooth



Driving forces behind Europa’s tectonics

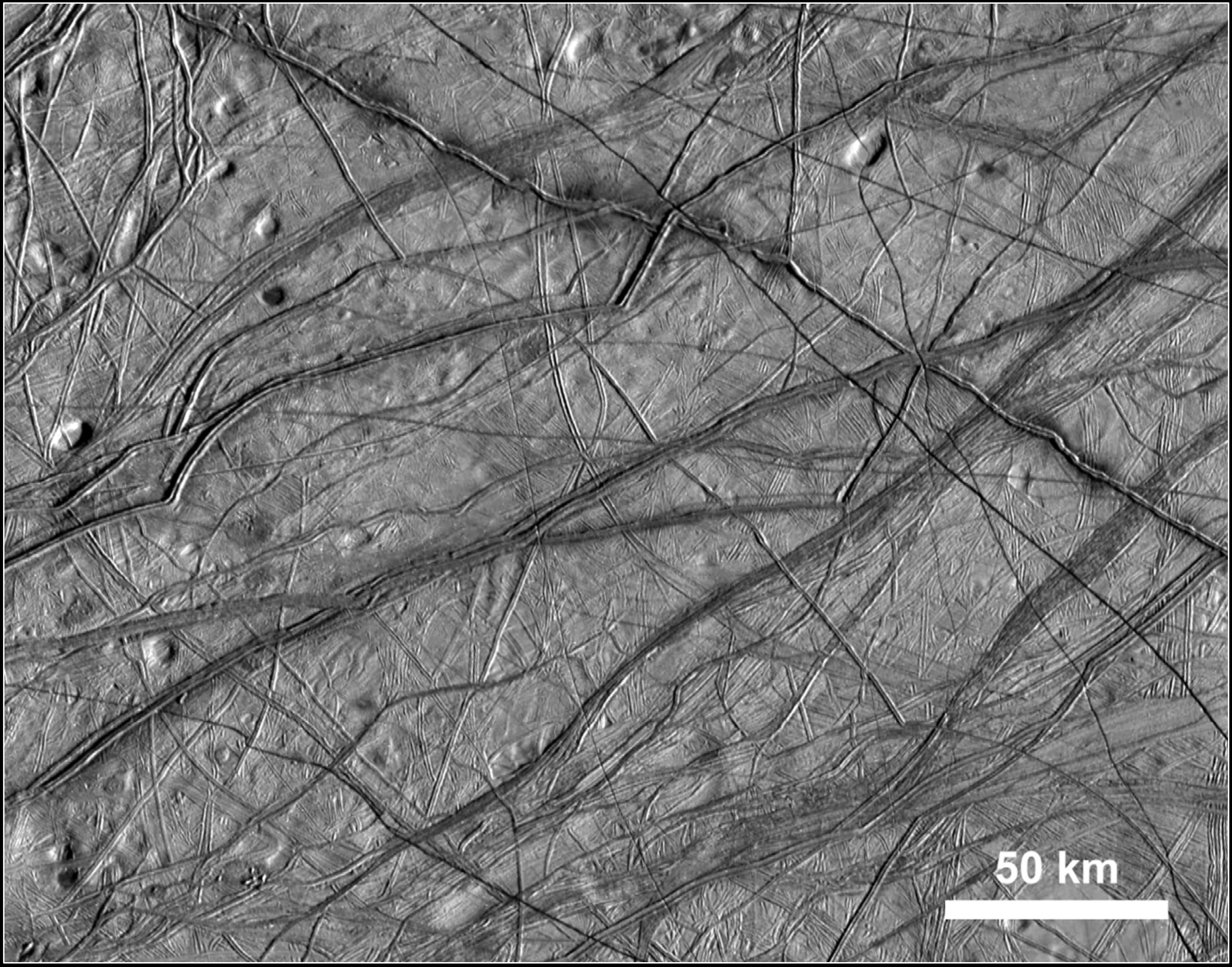
Primary sources of stress:

- Non-synchronous rotation
- Diurnal tidal forcing

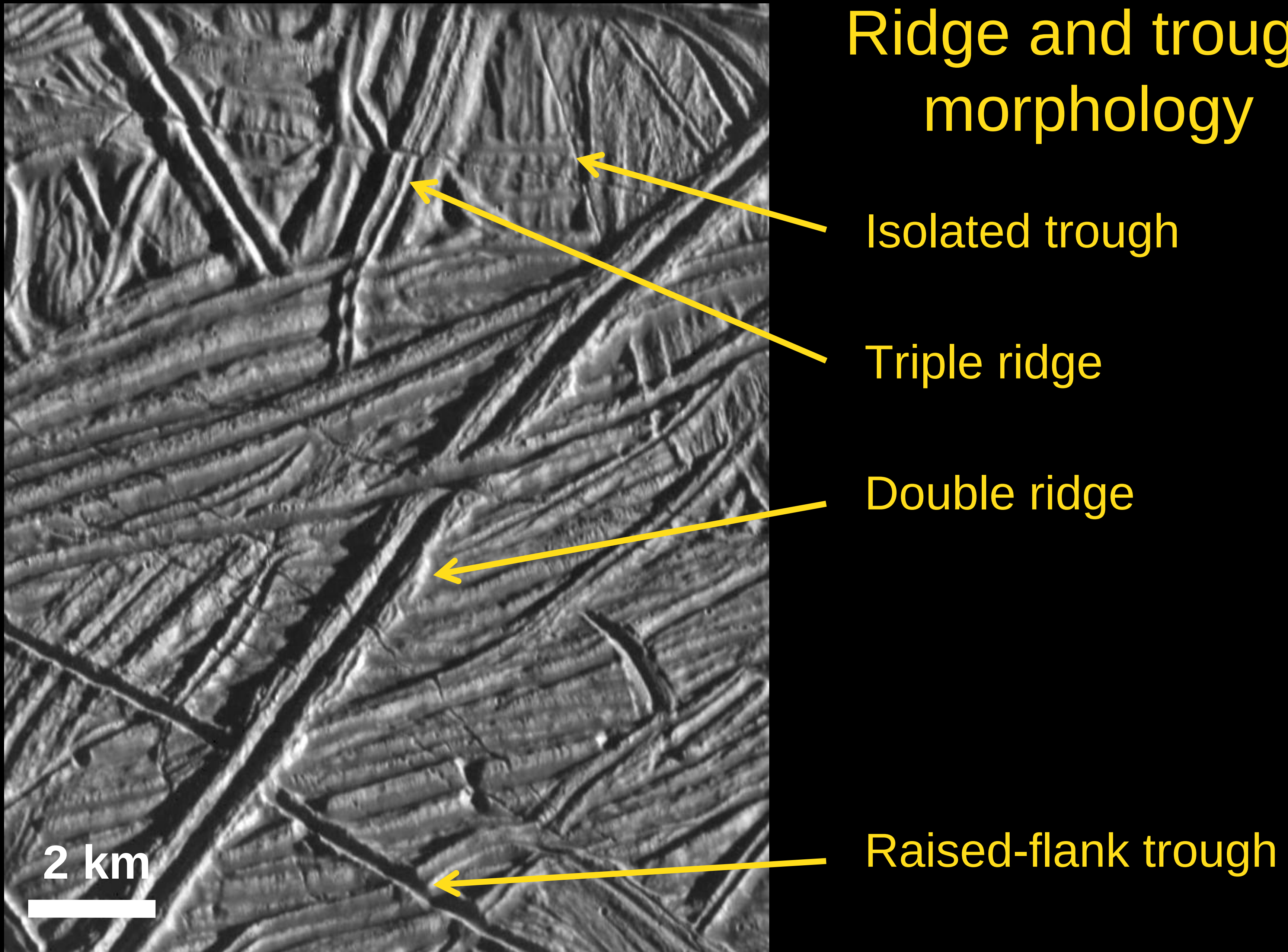
Additional sources of stress:

- Orbital evolution
- Polar wander
- Finite obliquity
- Ice shell thickening
- Endogenic forcing by convection and diapirism
- Secondary effects driven by strike-slip faulting and plate flexure

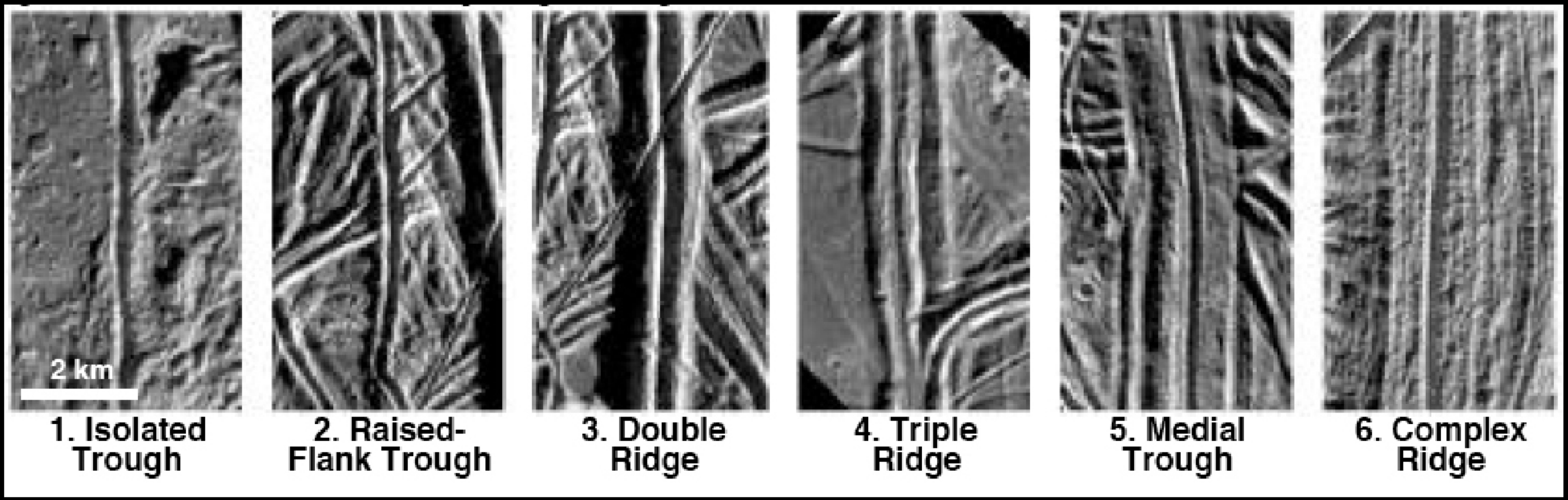
Ridges and Troughs


50 km

Ridge and trough morphology



Ridge and trough morphology

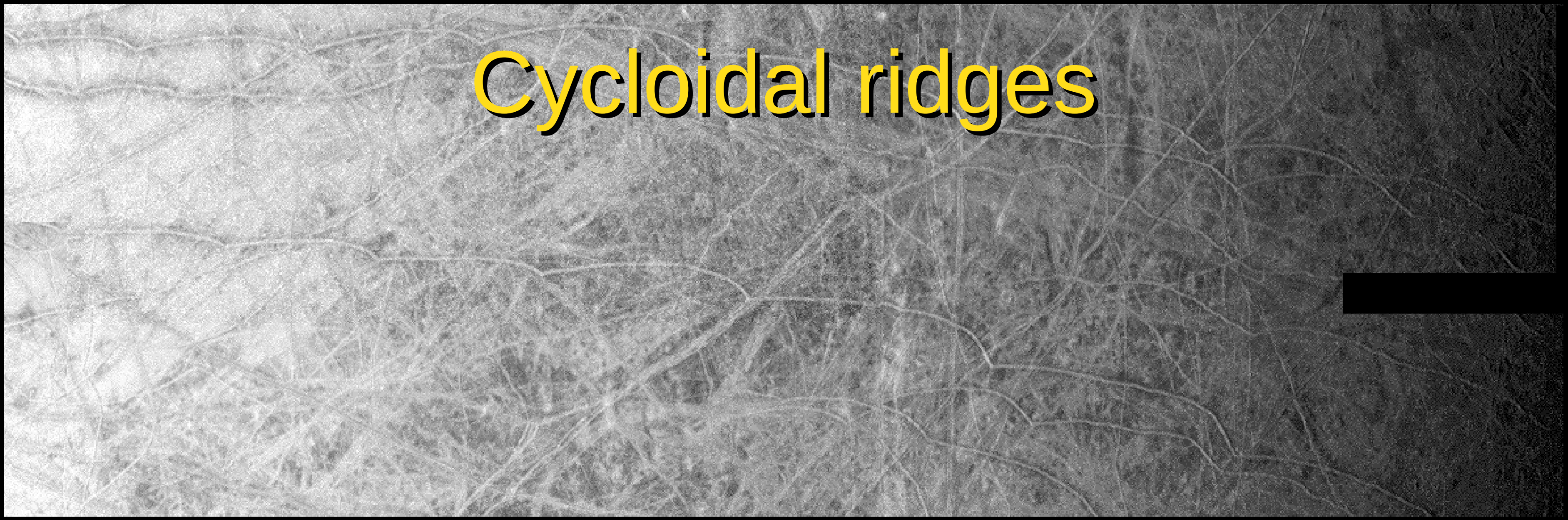


1. Isolated trough
2. Raised-flank trough
3. Double ridge
4. Triple ridge
5. Medial ridge
6. Complex ridge

2 km

Greenberg et al., 1998; Pappalardo et al., 1998

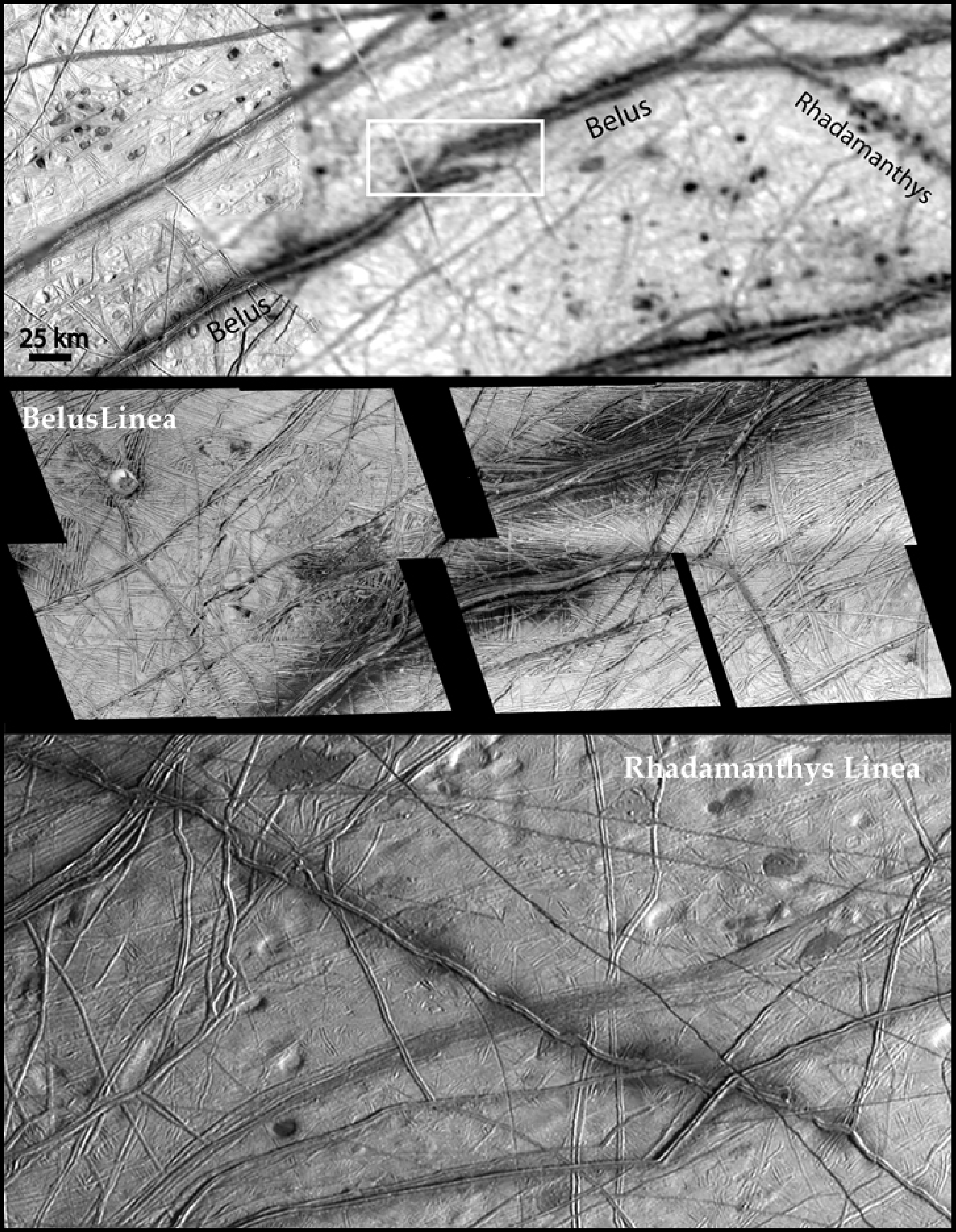
Cycloidal ridges



Cycloids are explained by changing tidal stresses

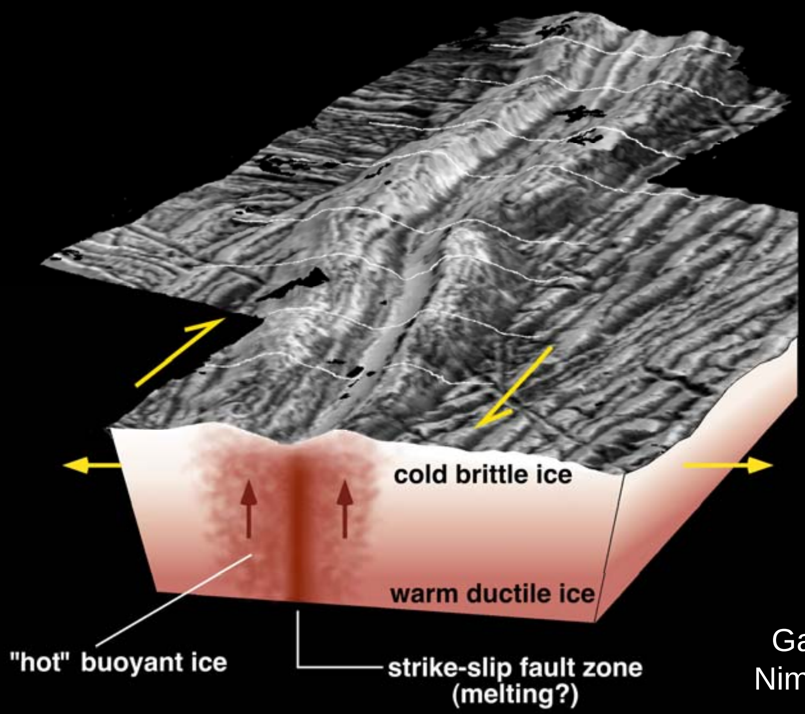
Ridge complexes

- Bright central ridge or ridges, flanked by patch deposits of low albedo material
- Dark material on either side of ridge flanks, can extend < 10 km
- Dark deposits may be patchy (e.g., Rhadamanthys Linea) or continuous (e.g., Belus Linea)
- Dark material appears to be relatively thin

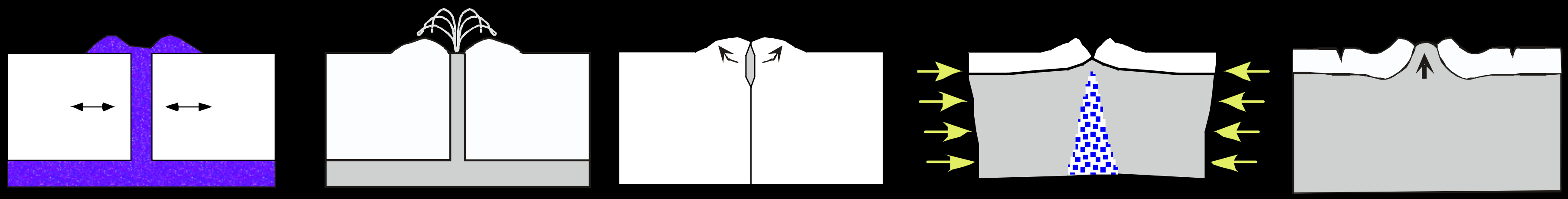


Formation mechanism: Shear deformation?

- Diurnal stresses drive strike-slip motion
- Frictional heating along discrete fracture reduces ice viscosity within corresponding shear zone
- Warm, low viscosity ice rises buoyantly toward surface creating a ridge
- Can potentially build few-100 m high ridge in 10 years



Gaidos and Nimmo 2000



Tidal pumping

Cryovolcanism

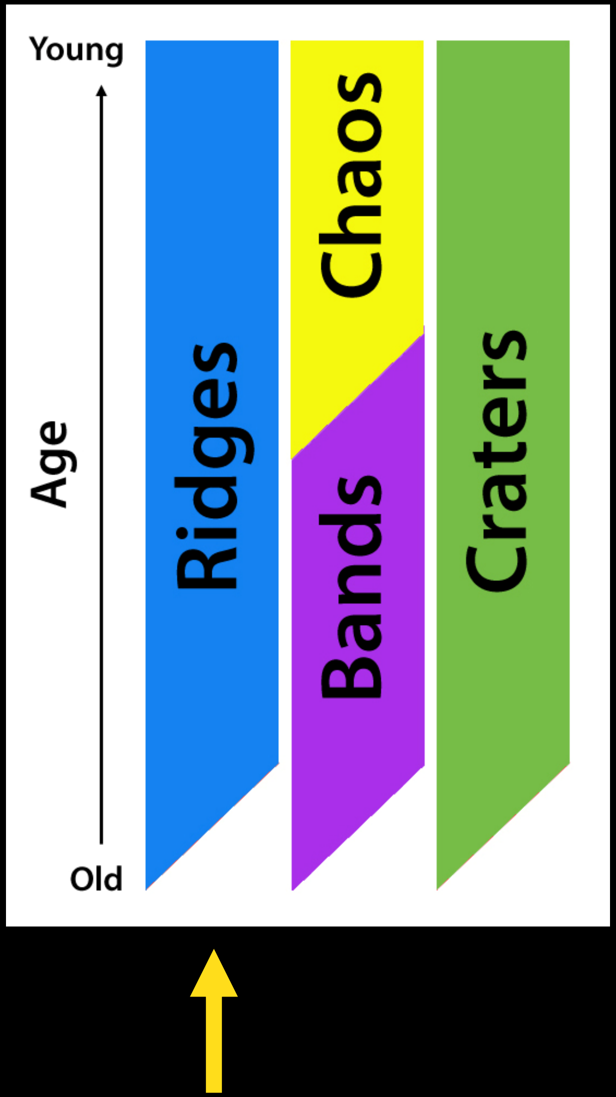
Ice wedging

Compression

Linear diapirism

Stratigraphic history of Ridges

- Ridges have formed throughout Europa's visible history
- They are found within the oldest background ridged plains
- The youngest features on Europa are troughs
- It is likely that fractures are still forming today, perhaps being reworked into ridges



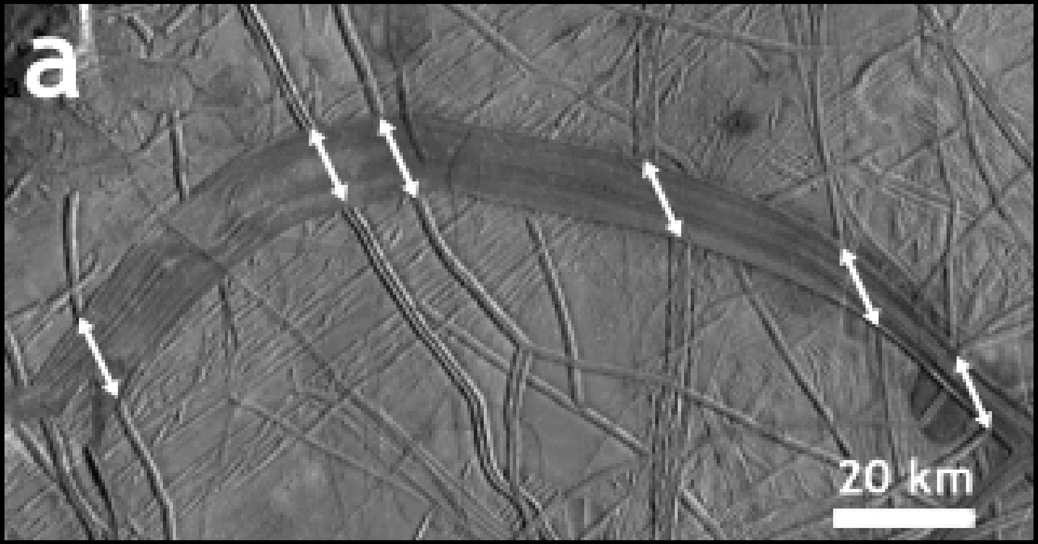
Would ridges make good landing sites?

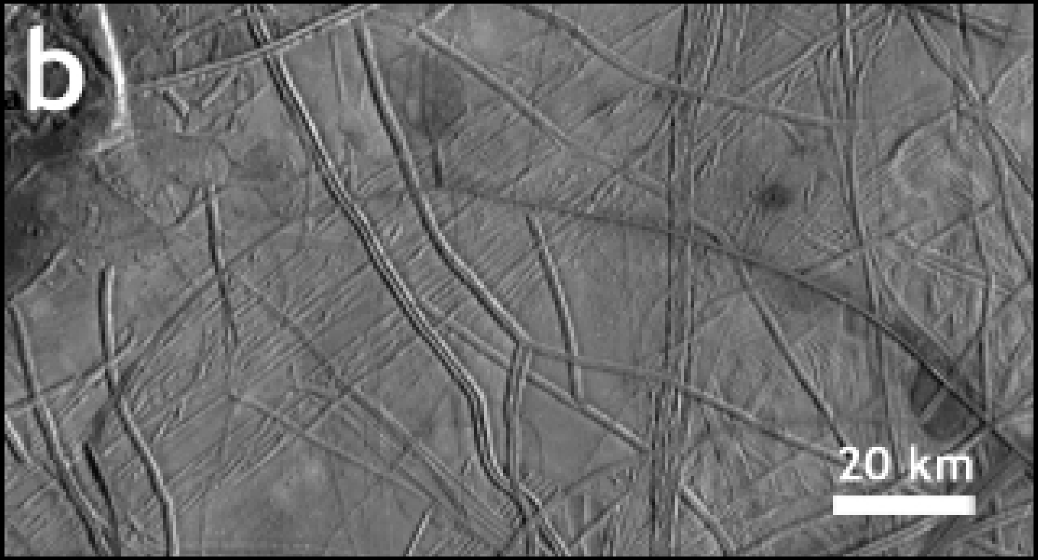
1. Subsurface communication? - Not certain
2. Young? - Yes, many are
3. Flat/Smooth? - No

A young ridge is probably not the best target for a lander

Bands

Pull-apart Bands

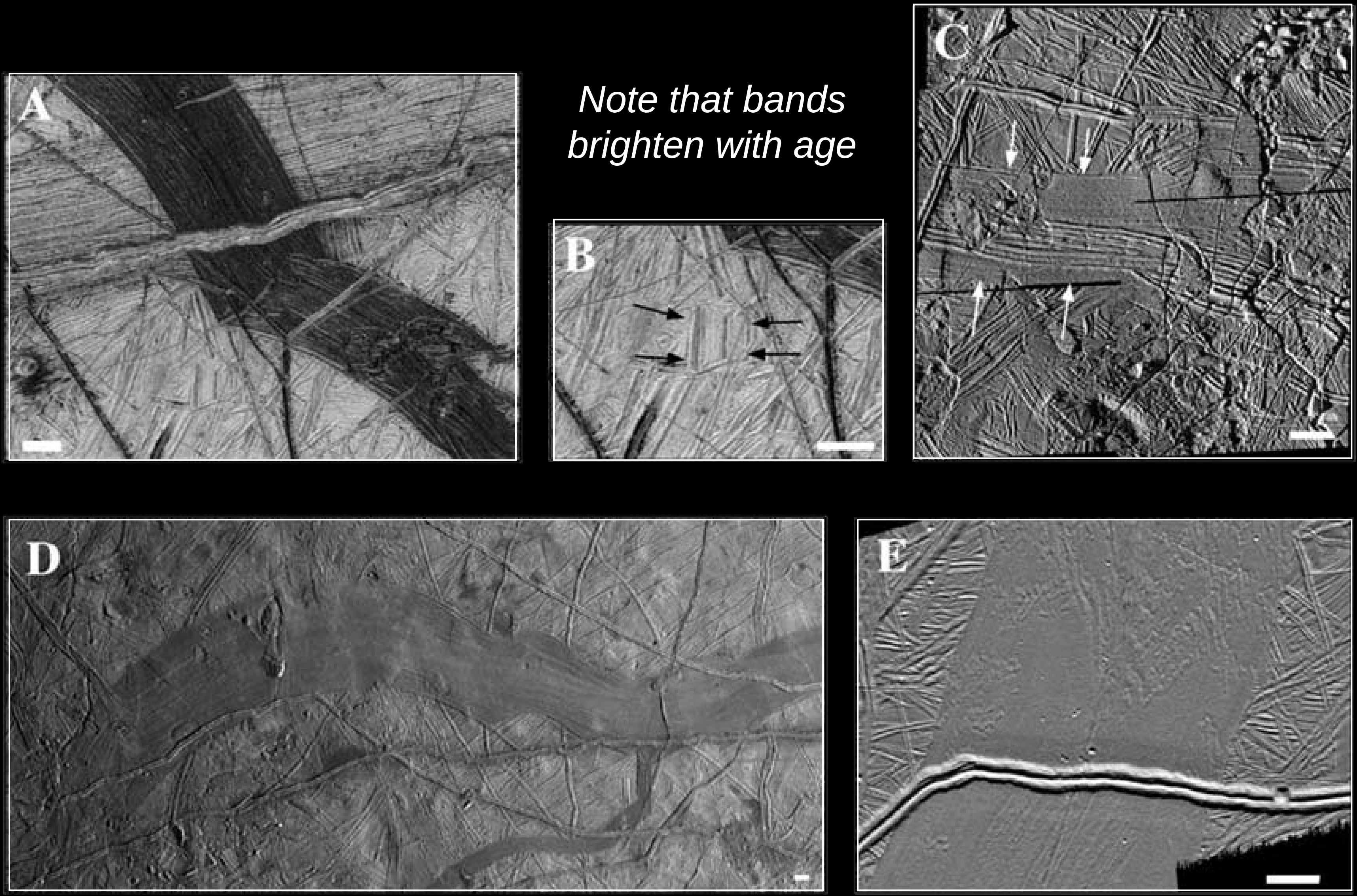




Separation and spreading of the icy crust

Pull-apart band morphology

Note that bands brighten with age

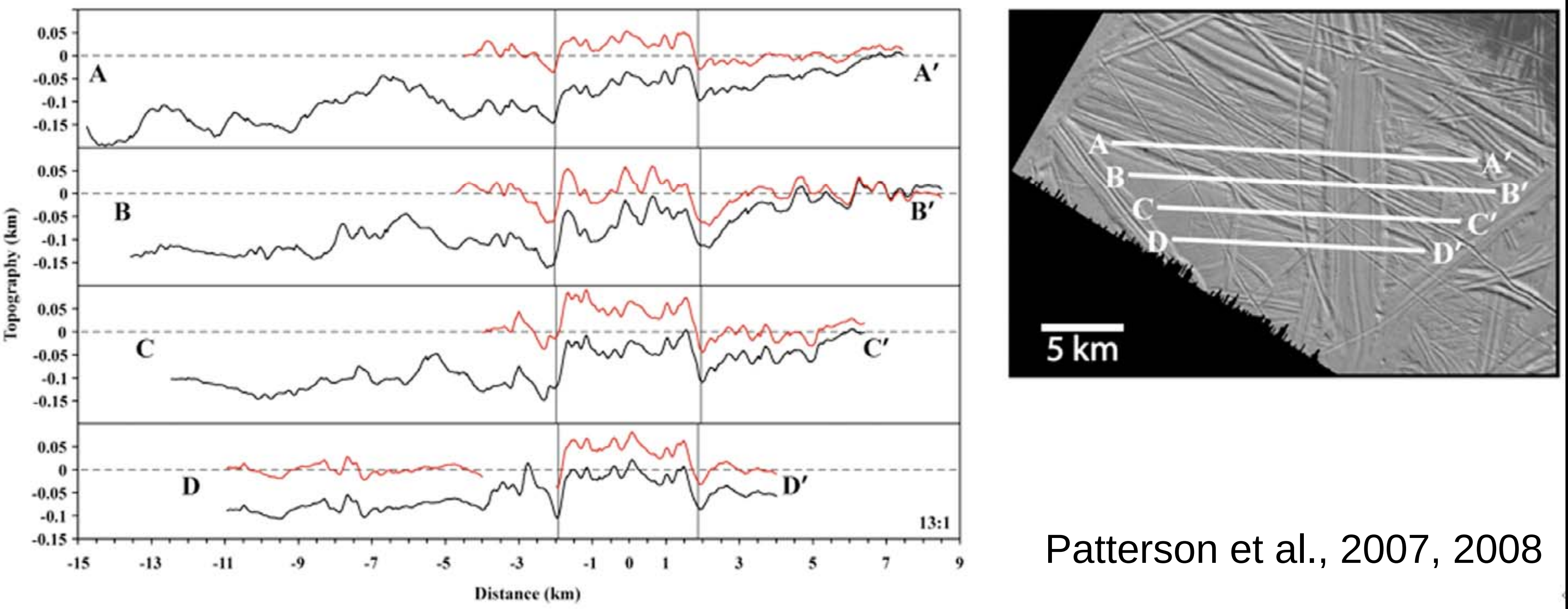


Scalebars = 5 km

Prockter et al., 2002

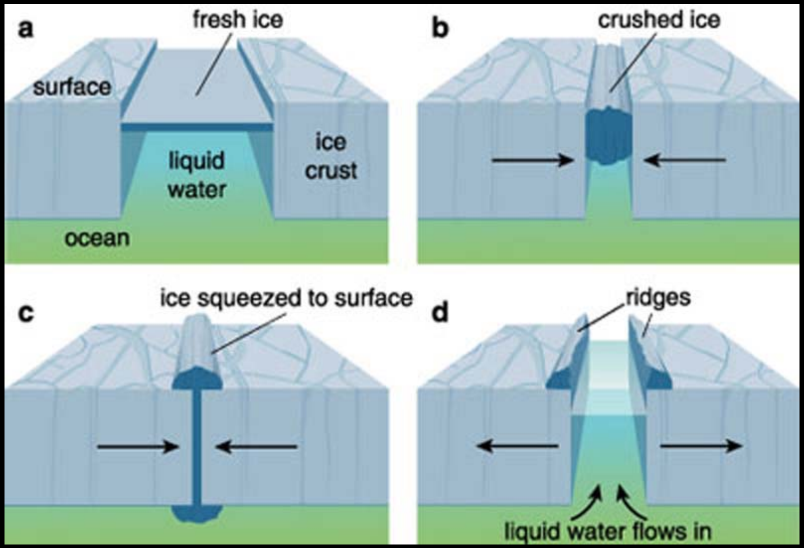
Band topography

- Ongoing studies suggest majority of bands stand higher than their surroundings
- Small-scale topography is rugged, even on smooth-appearing bands



Patterson et al., 2007, 2008

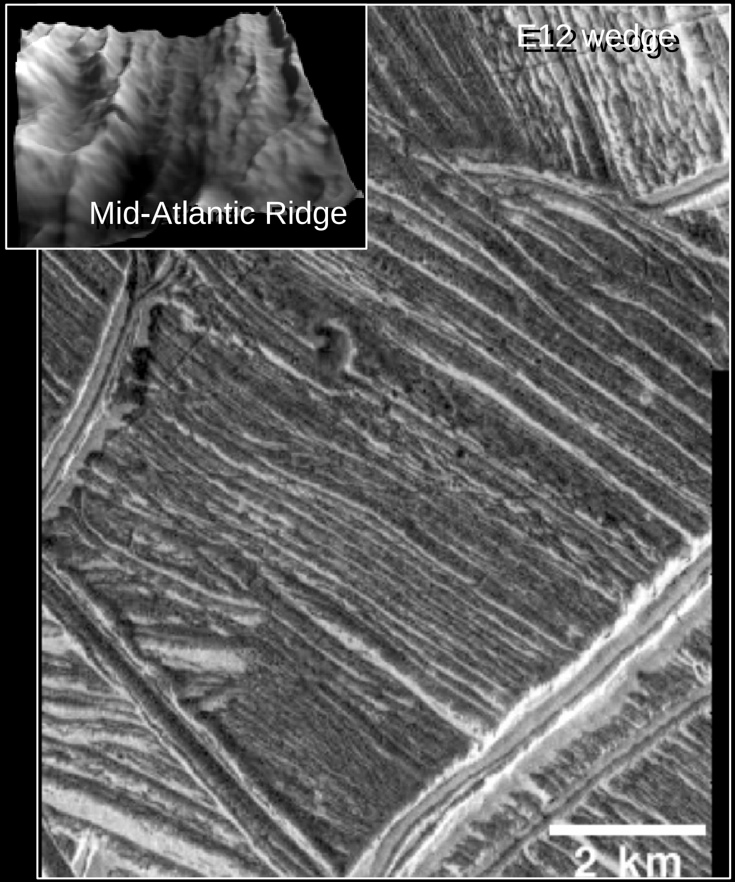
Models of pull-apart band formation



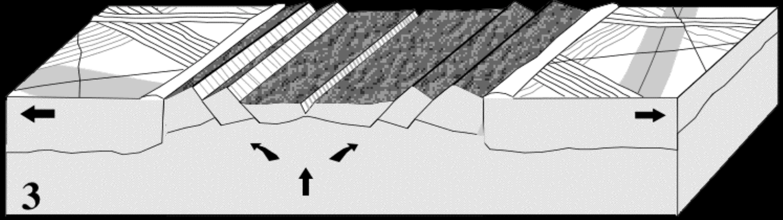
Pappalardo and Coon, 1996; Greenberg et al., 1998, 2002

Manga and Sinton, 2004

“Tidal pumping” model



Prockter et al., 2002

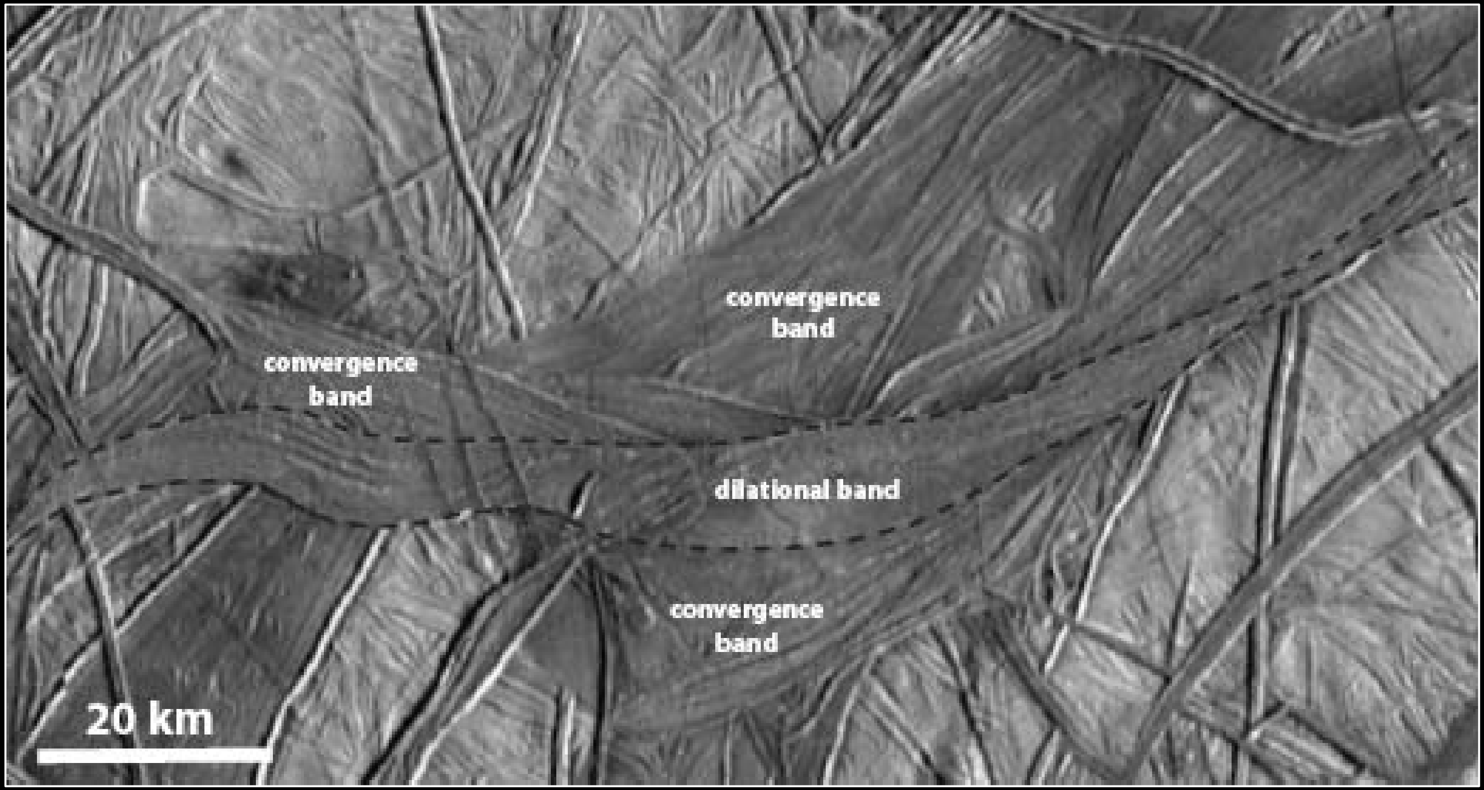


“Seafloor-spreading” model

Convergent Bands?

Some bands have margins that are difficult to reconstruct, and interior lineations that are not parallel to the margins

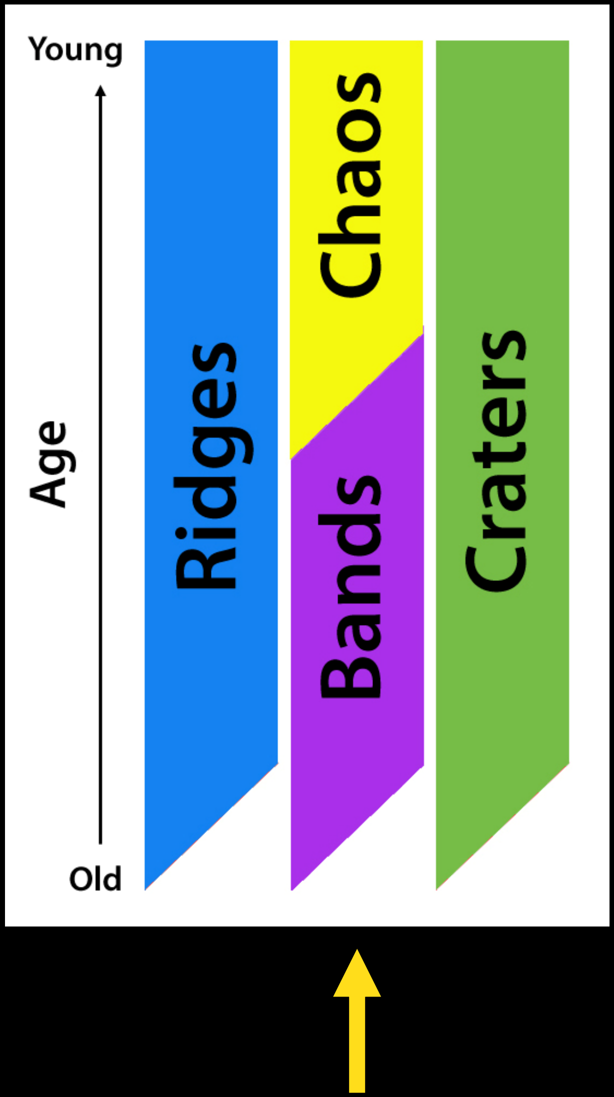
- suggested to be sites where compression is accommodated (e.g., Sarid et al., 2004)
- may be places where multiple overlapping bands have formed (Patterson et al., 2006)



Kattenhorn and Hurford, in press

Stratigraphic history of bands

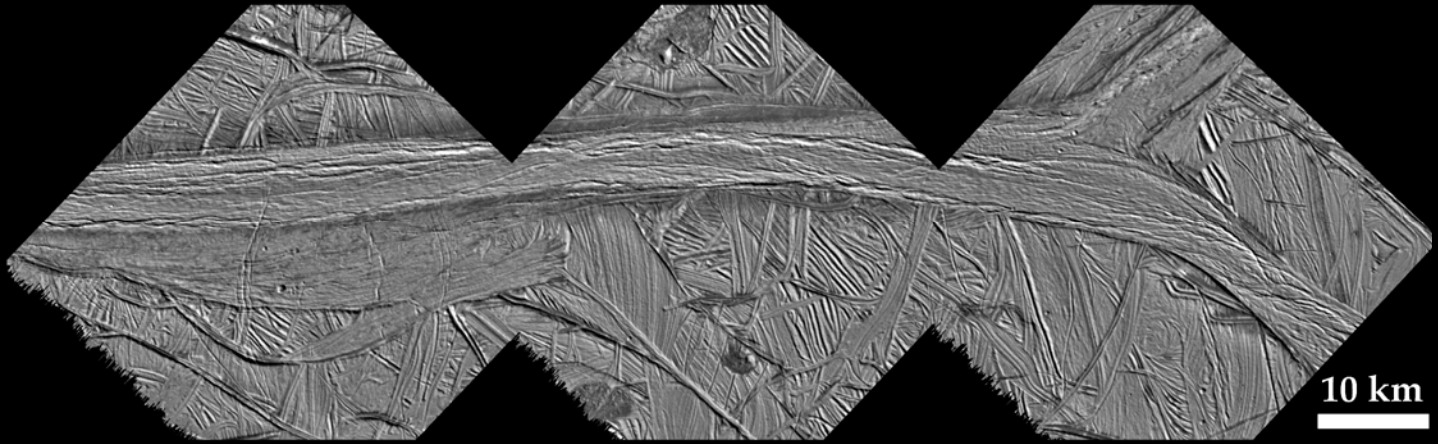
- Bands appear to be old-to-intermediate in Europa's visible history
- Bands brighten with age - oldest bands are bright, youngest bands are dark
- Bands are overlain by chaos and lenticulae, but not the other way around, implying that bands formed earlier in Europa's history



Would bands make good landing sites?

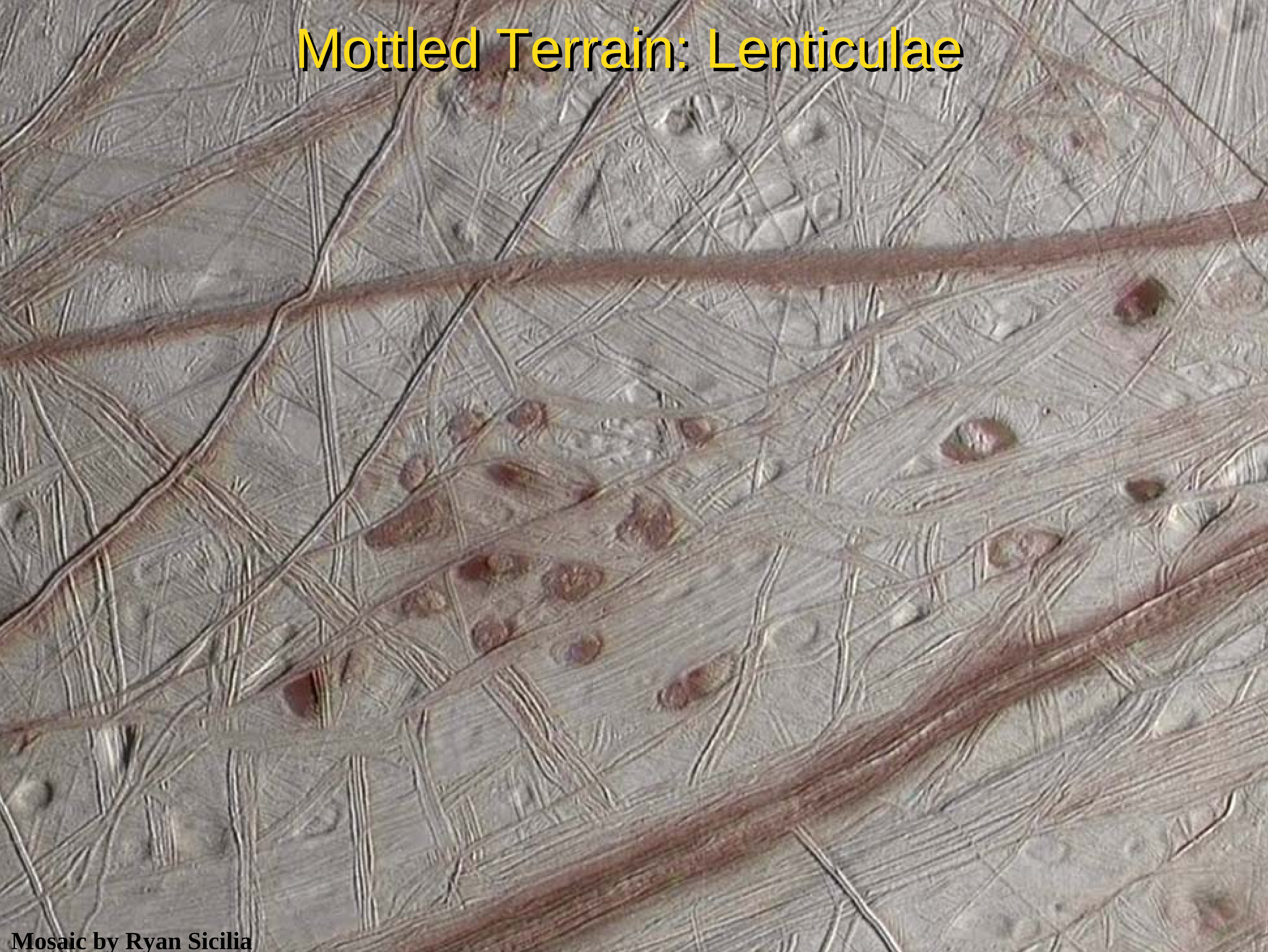
1. Subsurface communication? - Yes
2. Young? - No
3. Flat/smooth? - No

A young band is not a good target for a lander



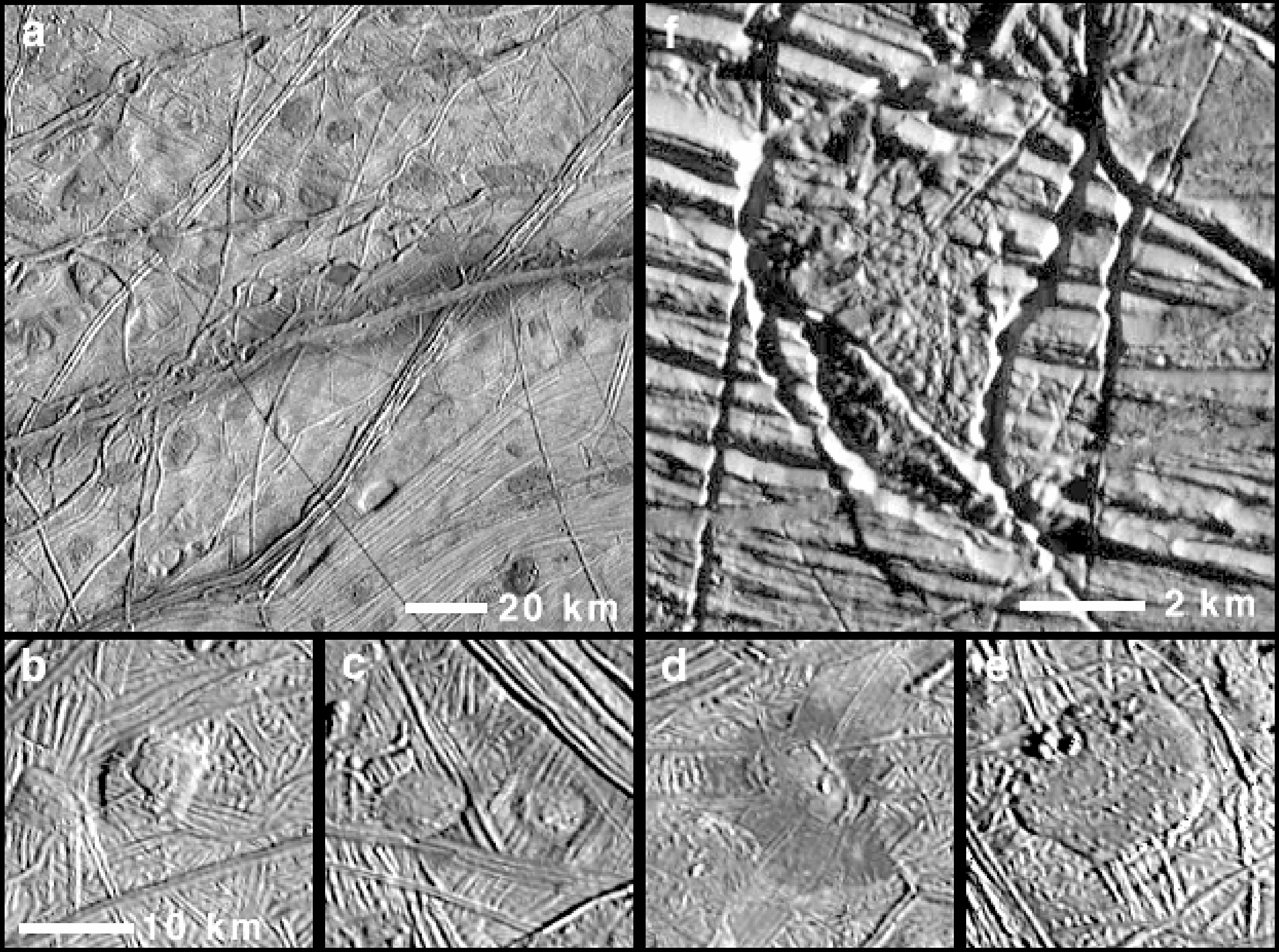
Chaos and Lenticulae

Mottled Terrain: Lenticulae

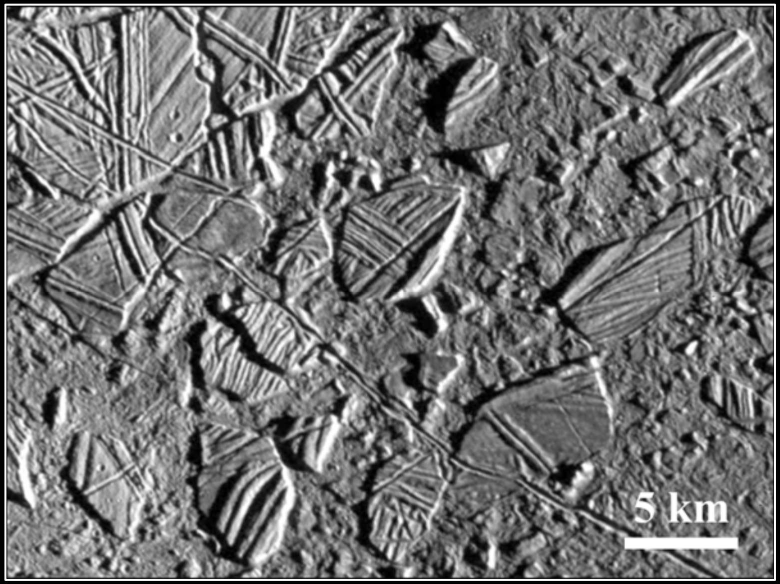


Mosaic by Ryan Sicilia

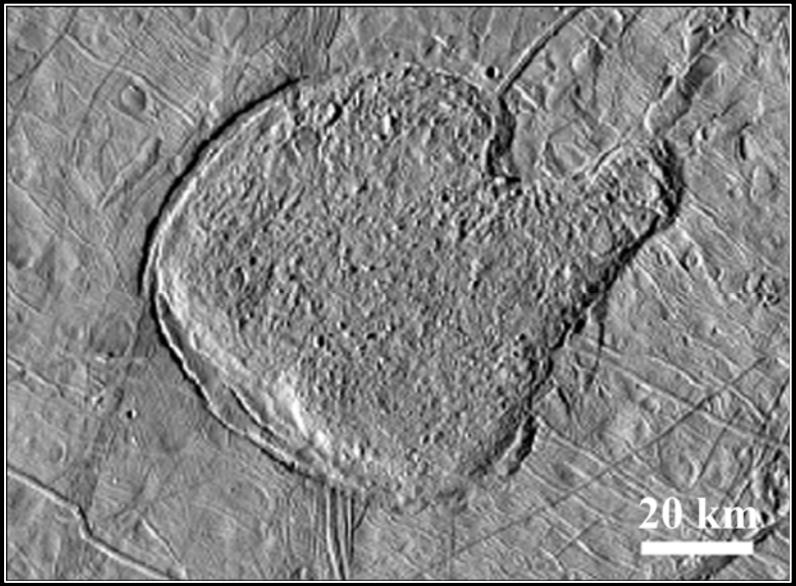
Lenticula morphology



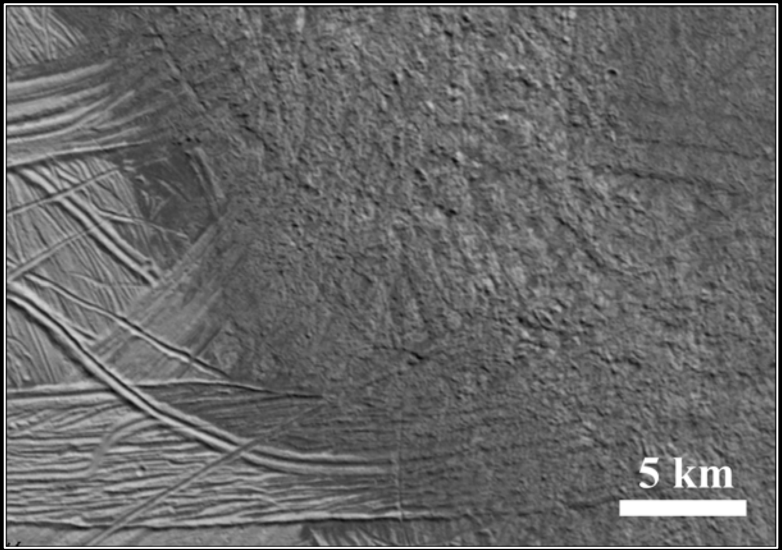
Chaos morphology



Conamara Chaos



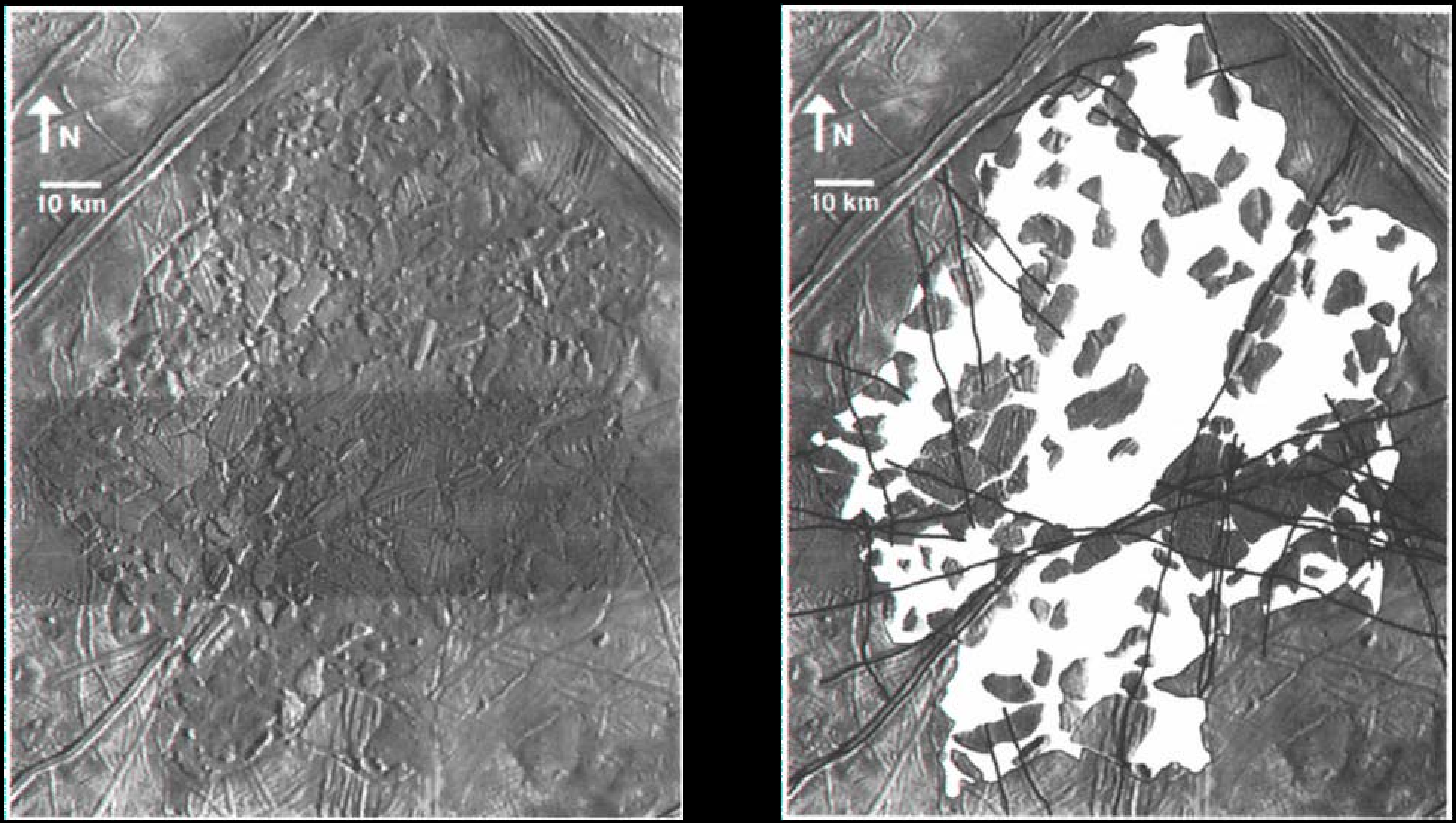
Murias Chaos



Thrace Macula

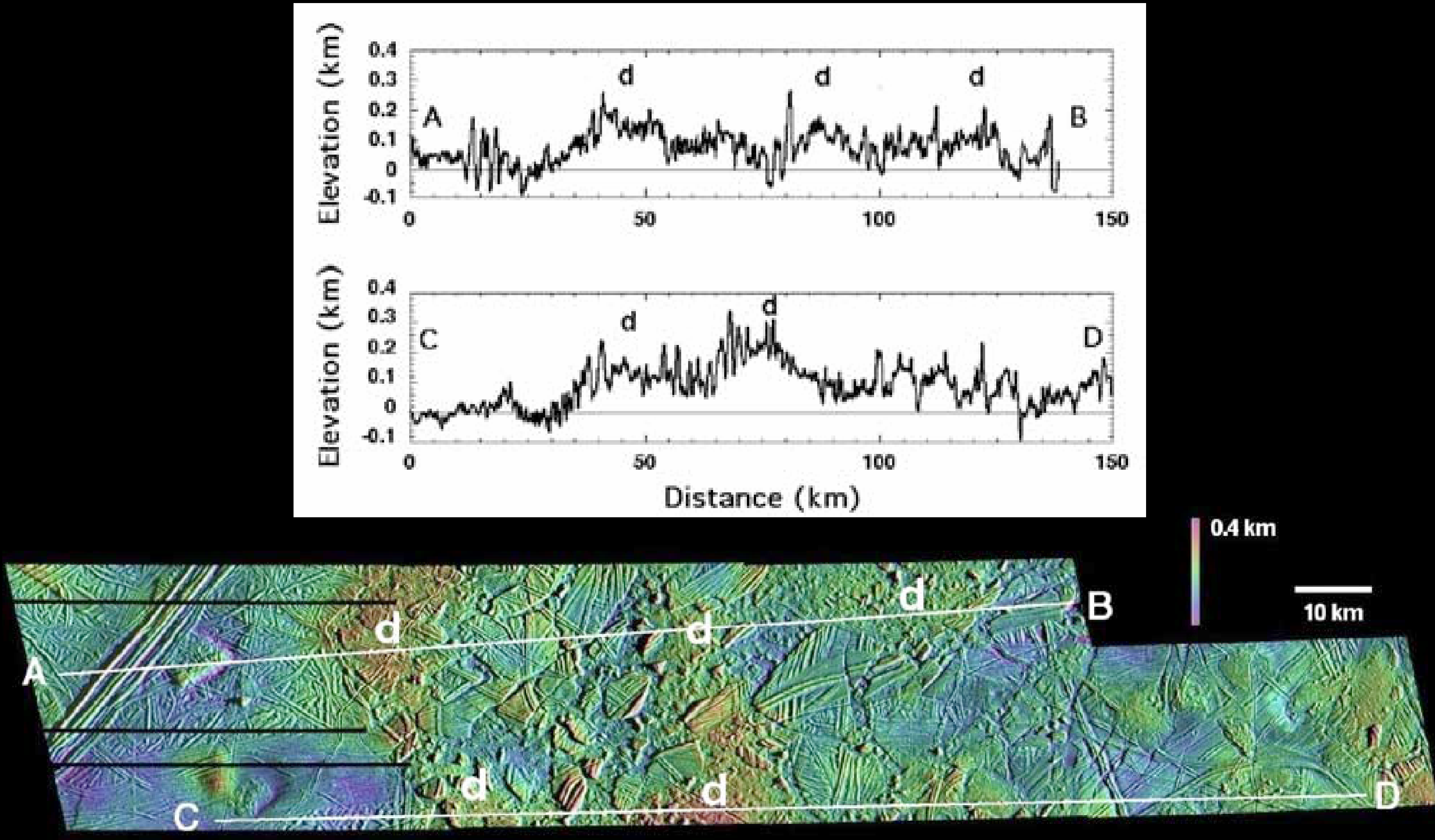
Conamara Chaos

Conamara Chaos



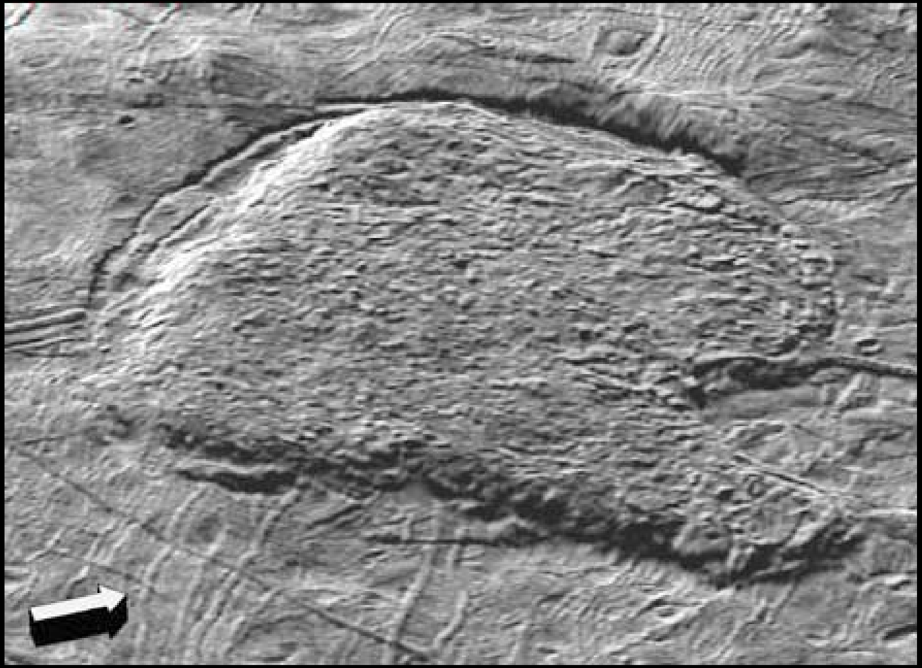
Spaun et al., 1998

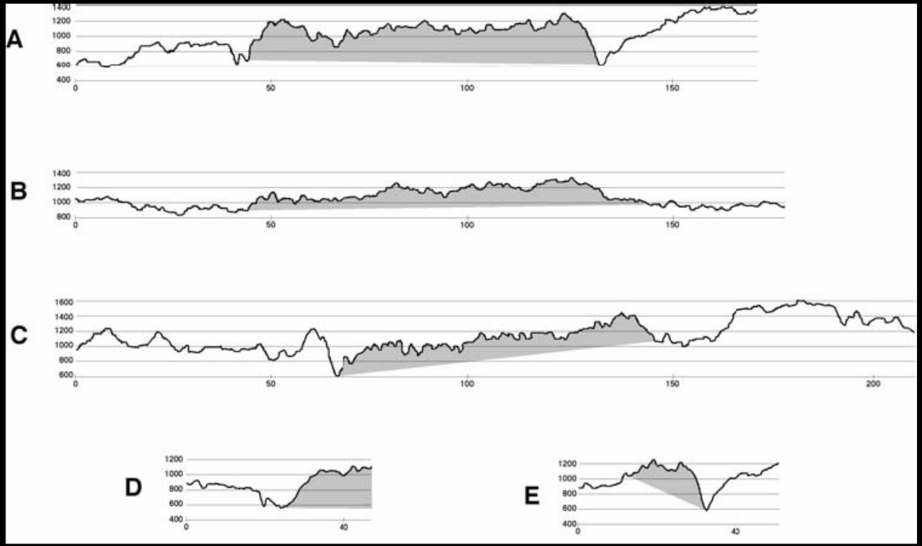
Conamara Chaos topography

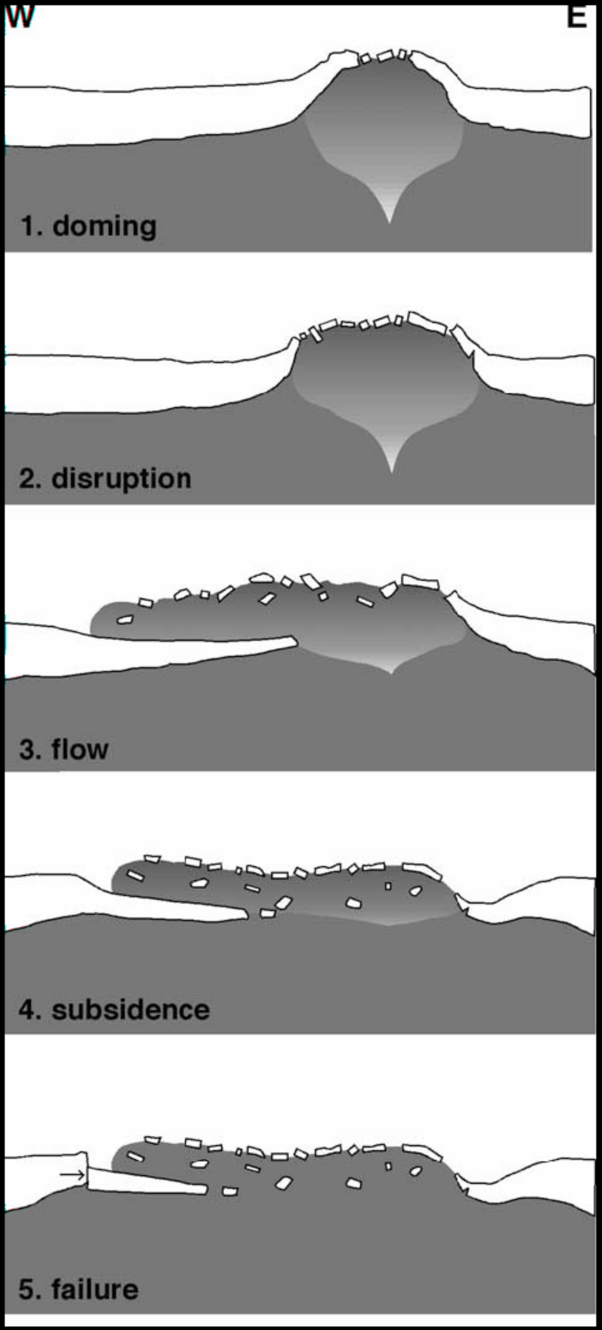


Schenk and Pappalardo, 2004

Murias Chaos

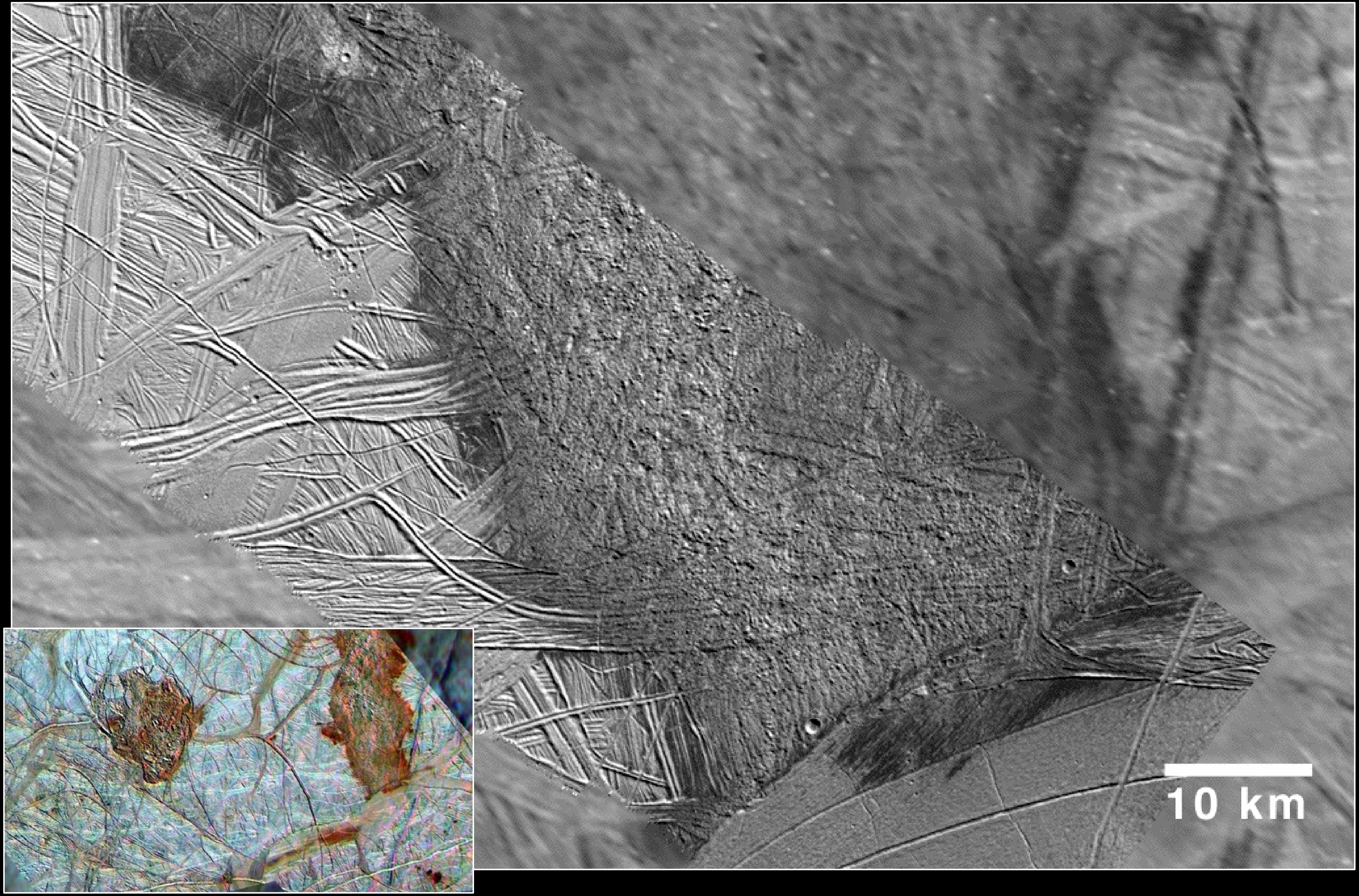




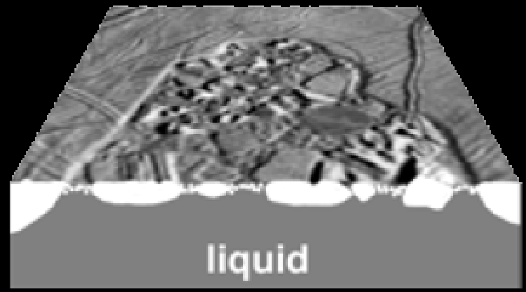


Figuredo et al., 2002

Thrace Macula



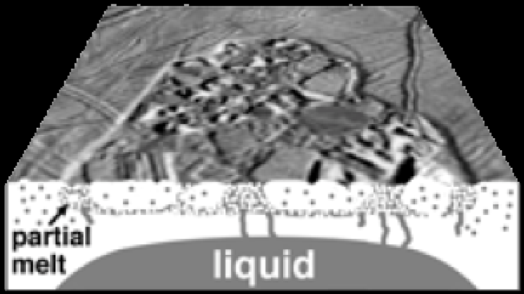
Models of Chaos Formation



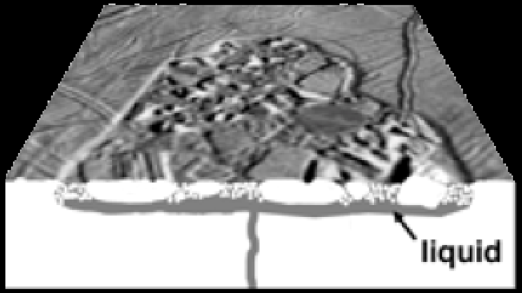
Melt-through

Diapirism

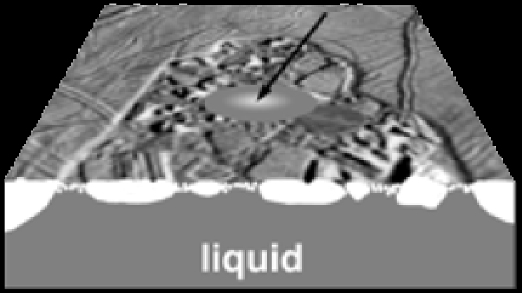
Brine mobilization and diapirism



Brine mobilization and melt-through



Sill formation

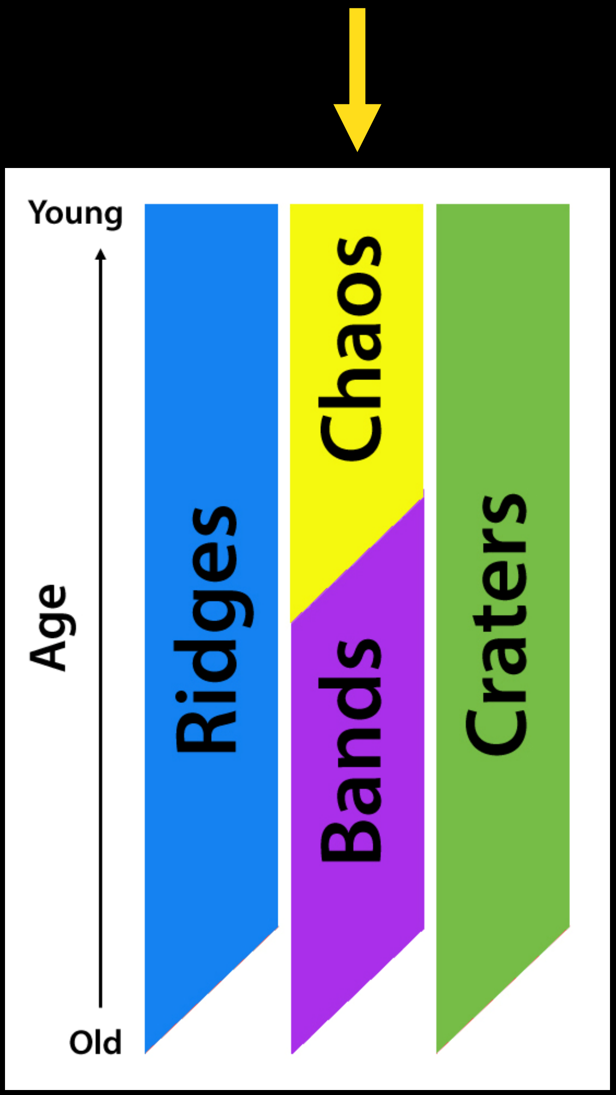


Impact

Collins and Nimmo, in press

Stratigraphic history of chaos and lenticulae

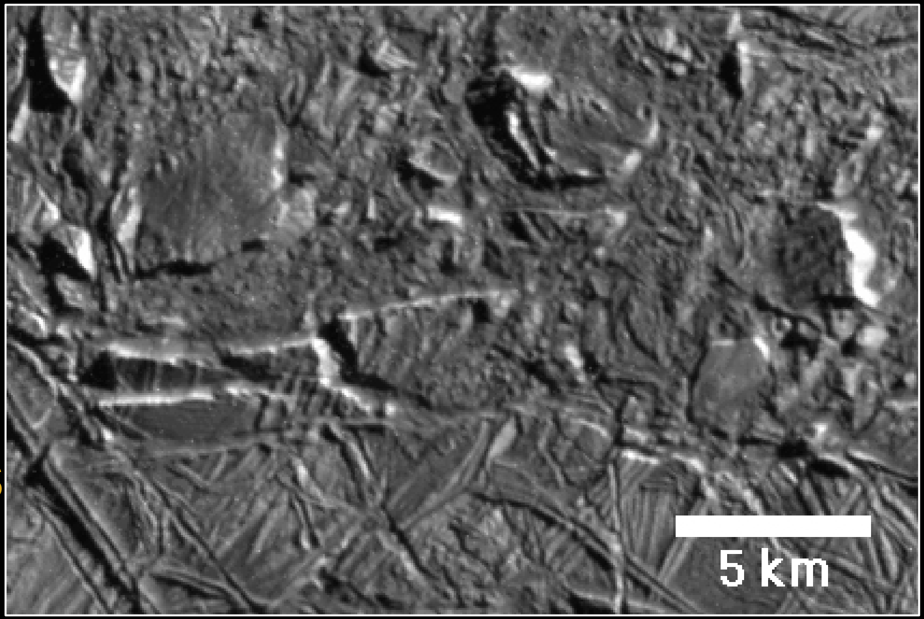
- Chaos and lenticulae appear to be relatively recent in the stratigraphic record
- A small number of chaos regions are disrupted by other chaos, or crosscut by linear troughs
- Chaos crosscut bands, bands do not crosscut chaos



Would chaos or lenticulae make good landing sites?

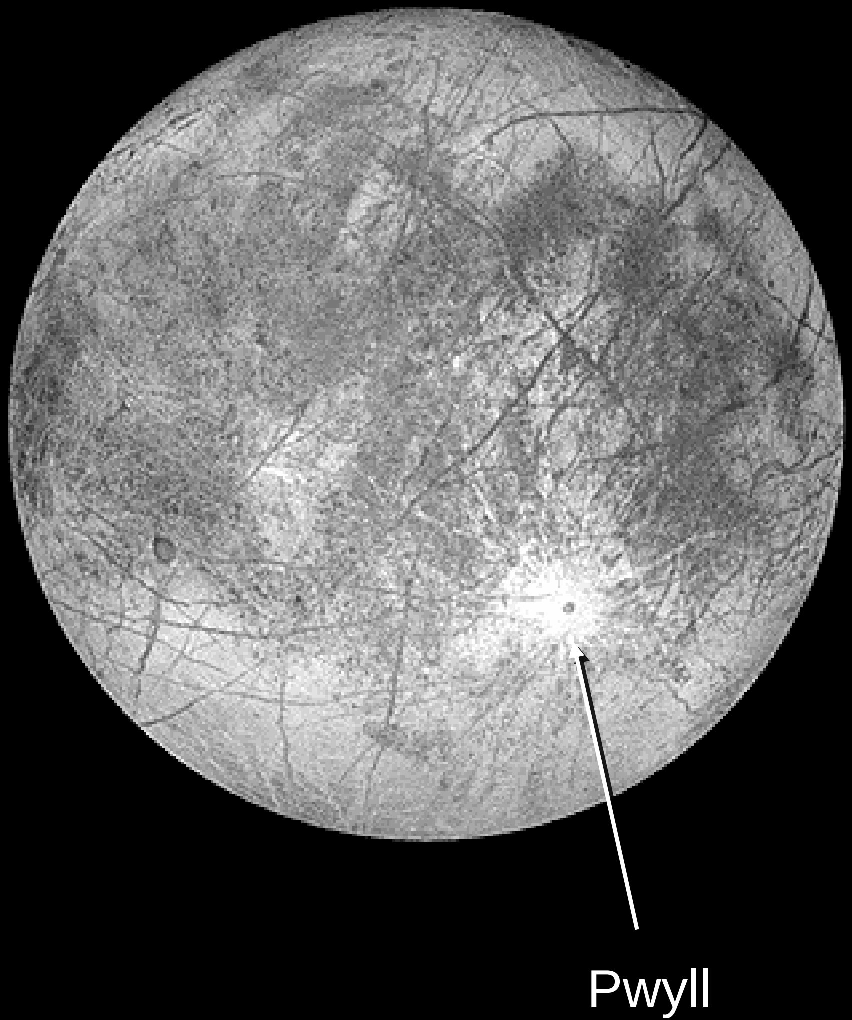
1. Subsurface communication? - Yes
2. Young? - Yes
3. Flat/smooth? - Some areas

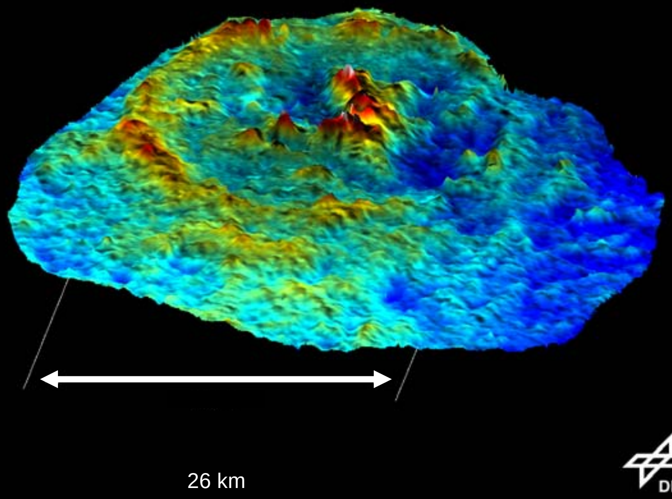
Chaos and/or lenticulae regions are attractive candidates for a lander, relatively safe, flat areas can be found

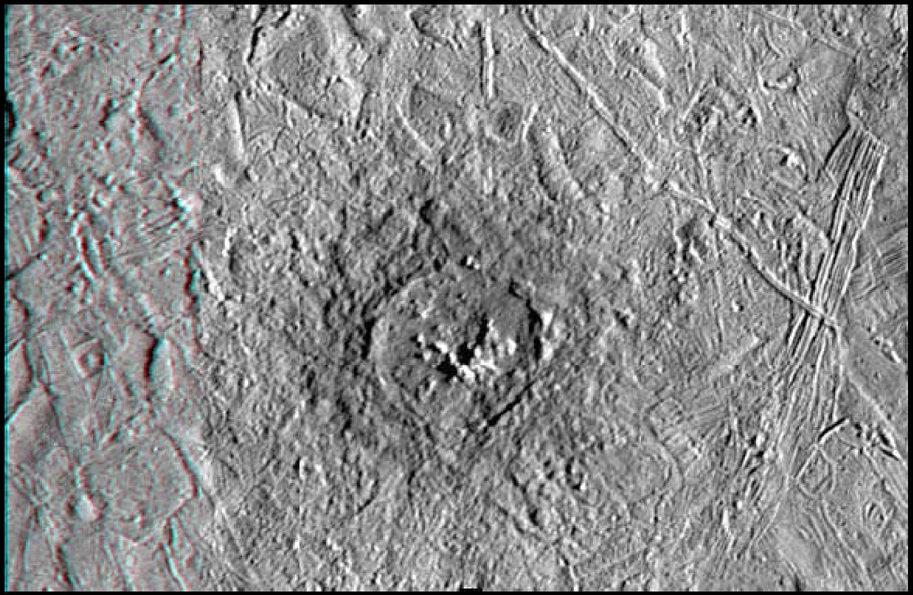


Impact Features

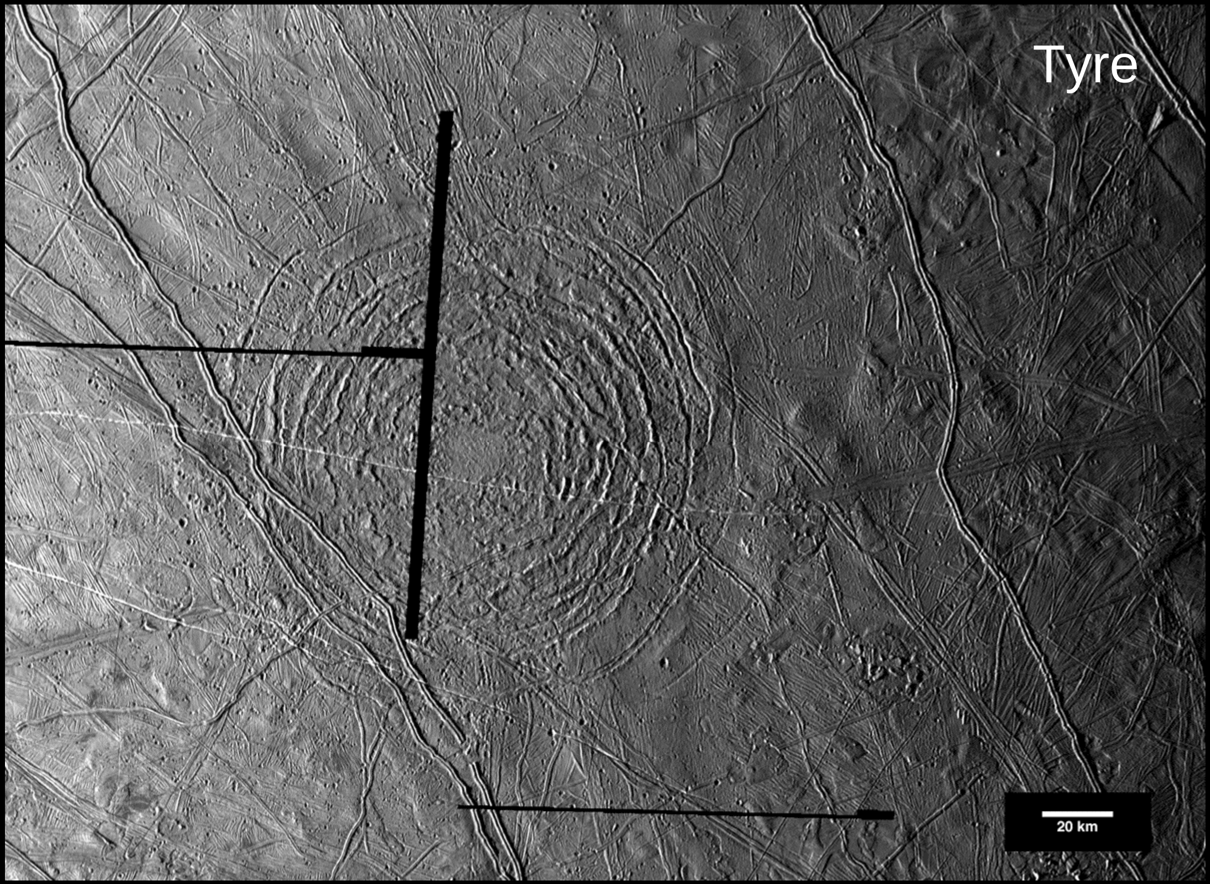
Youngest large crater on Europa - Pwyll

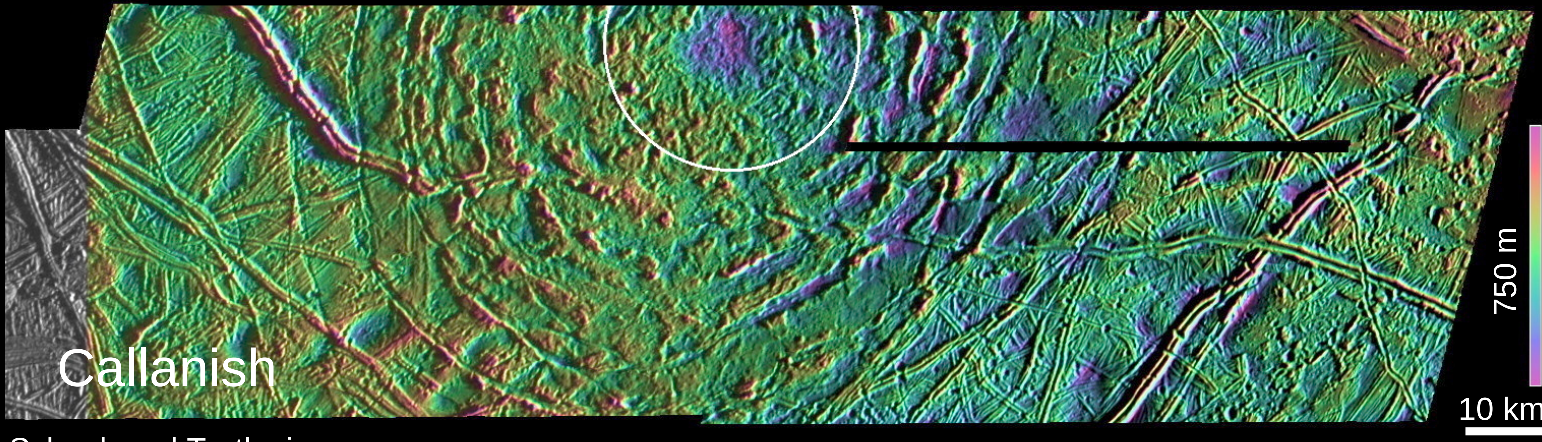






Multi-ring basins: Tyre and Callanish

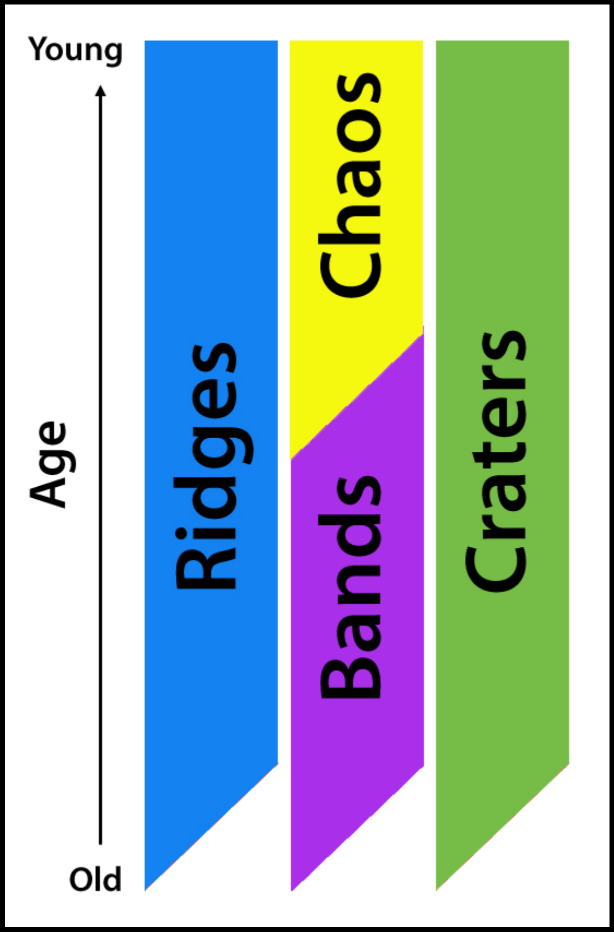




Schenk and Turtle, in press

Stratigraphic history of impact craters

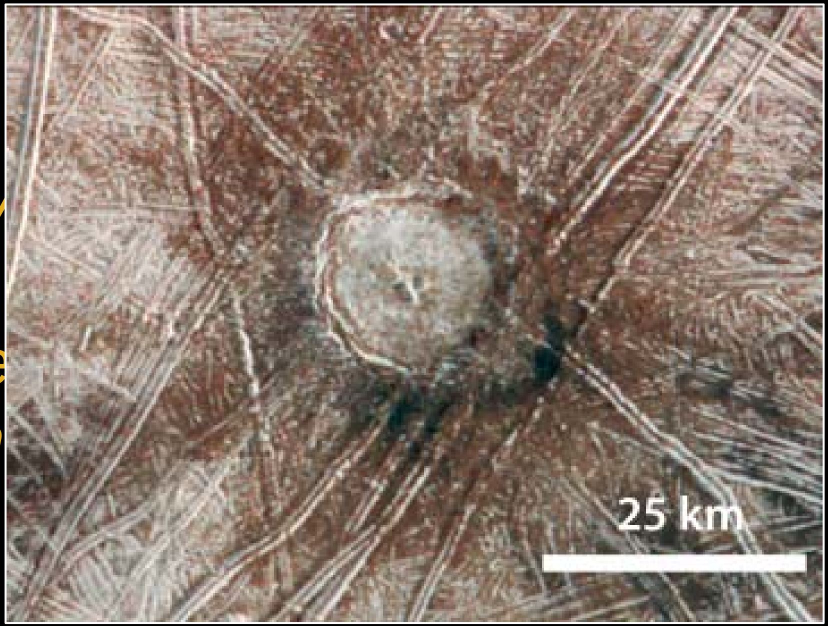
- Only 15 known craters greater 10 km in diameter, and only 3 larger than 25 km diameter
- Most small craters are secondaries
- Impact craters have formed throughout Europa’s visible history
- Few impact features are crosscut by other features



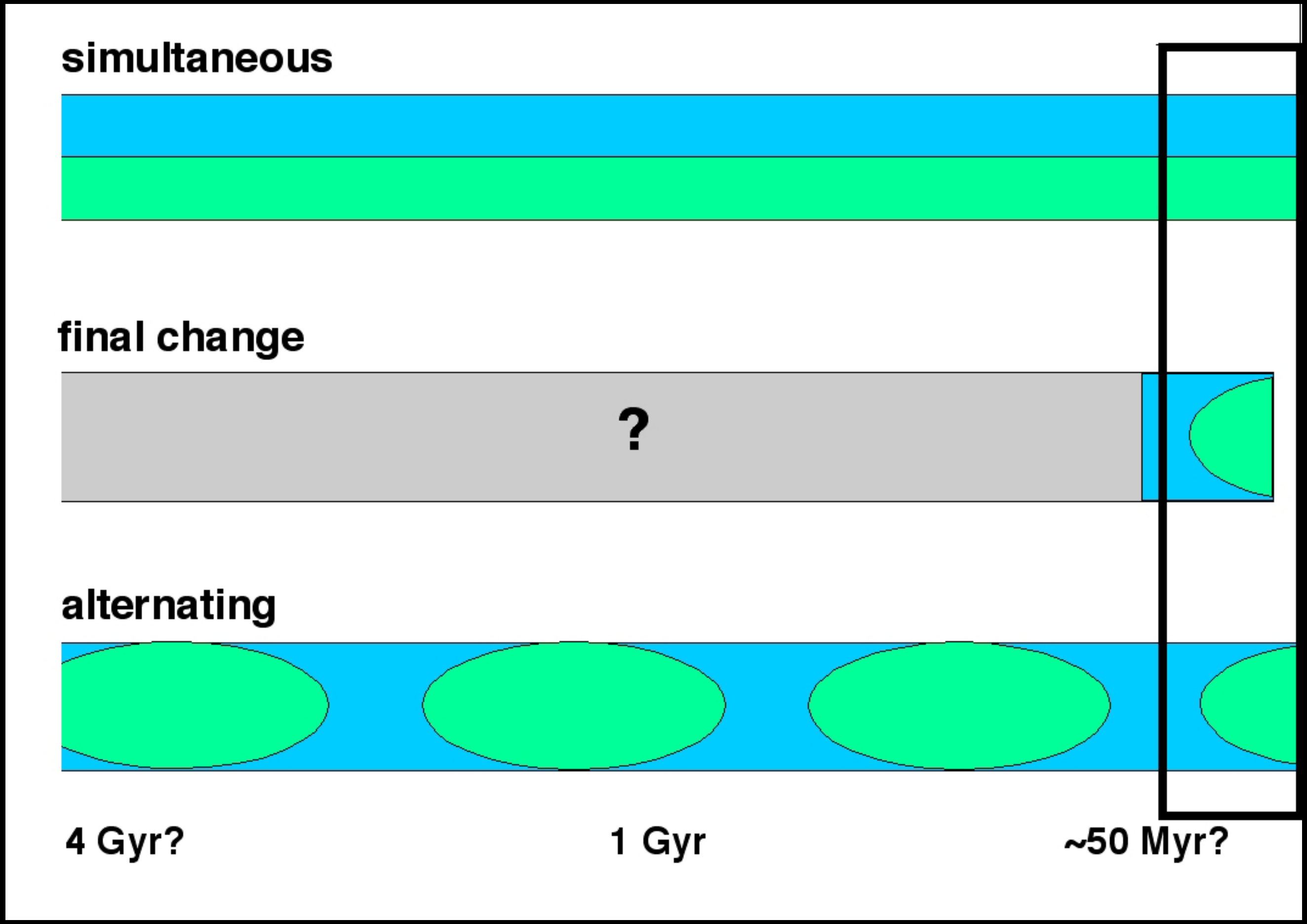
Would impact features make good landing sites?

1. Subsurface communication? - Yes
2. Young? - Yes
3. Flat/smooth? - No

Impact features could make good landing sites since they have potentially excavated unmodified material. However, the ruggedness of the terrain would have to be overcome



Europa's geologic history



Vertical (e.g., chaos) deformation

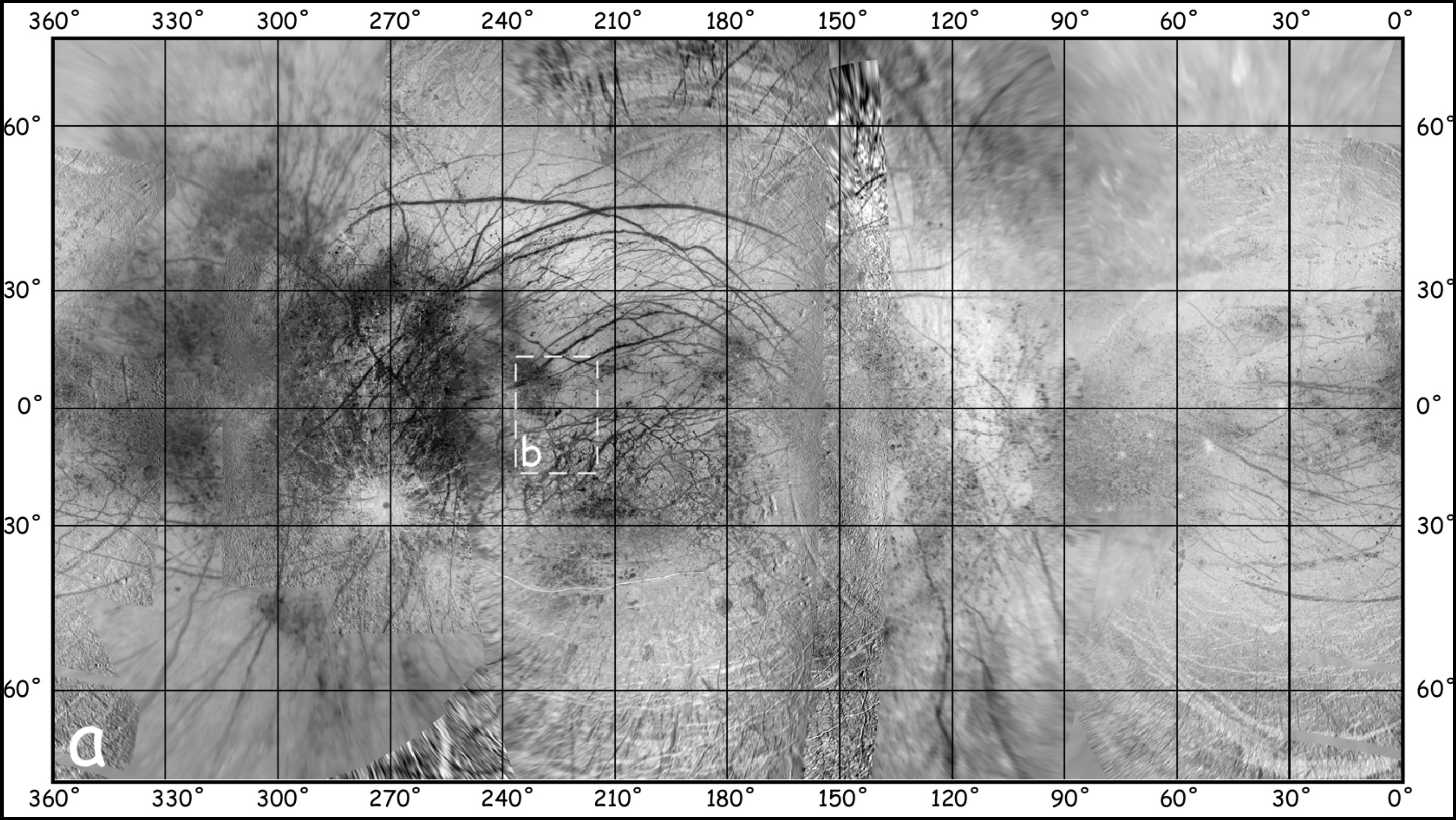
Lateral (e.g., pull-apart band) deformation

Figueredo and Greeley 2004

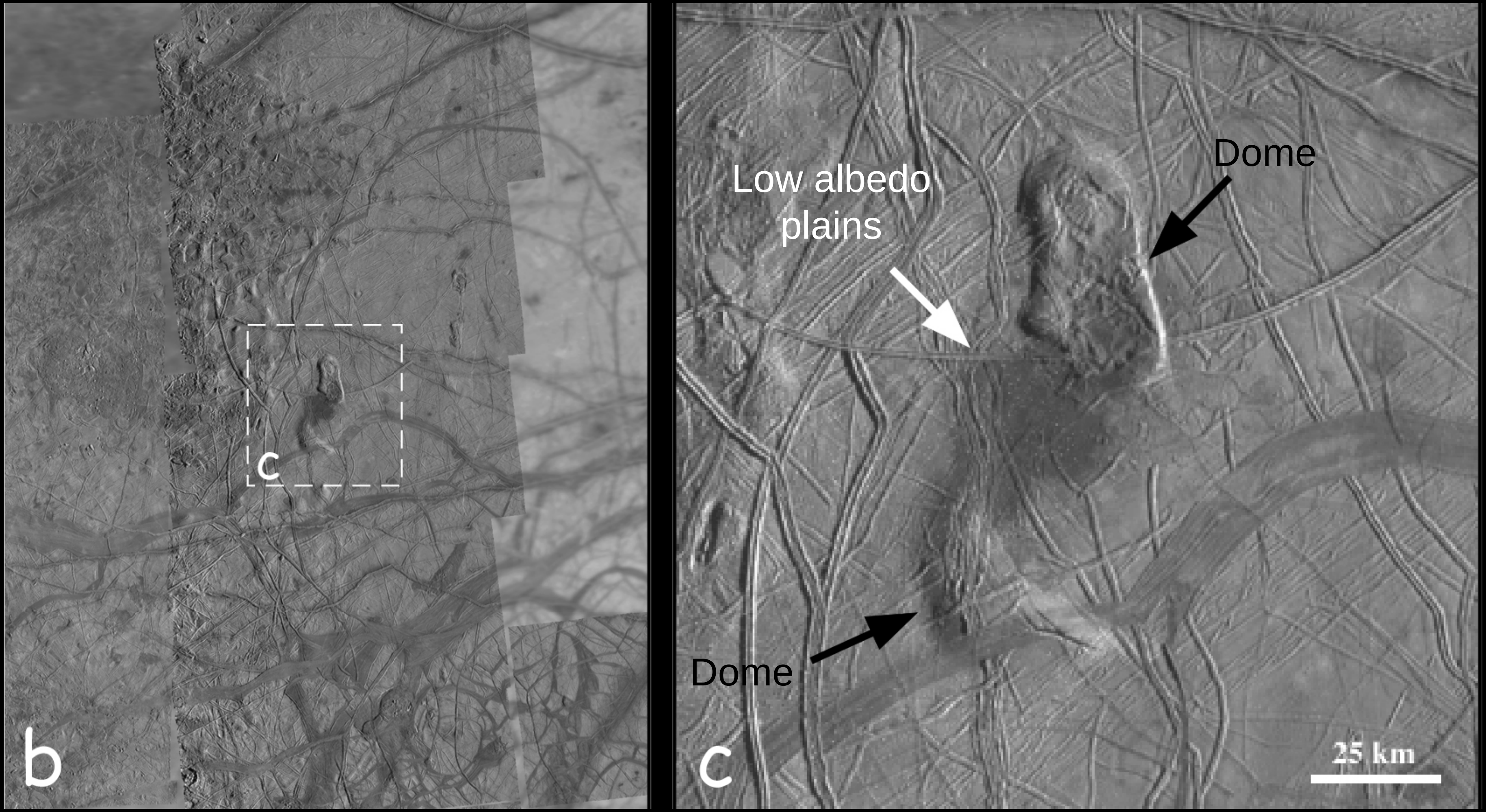
Implications of Europa's surface geology for landing sites

- Impact features and chaos are the most likely places where subsurface material has been brought to the surface, and are probably the best places to send a lander
- We have several models for feature formation but, with the exception of impact craters, we don't really know which ones are correct. We need:
  - Further modeling on role of liquid water and salts within Europa's ice shell
  - Better understanding of the role of tidal heating (global, regional, and local scales)
  - Better understanding of ice rheology under Europa conditions
  - Global topographic mapping and imaging at high and regional resolutions and under uniform lighting conditions

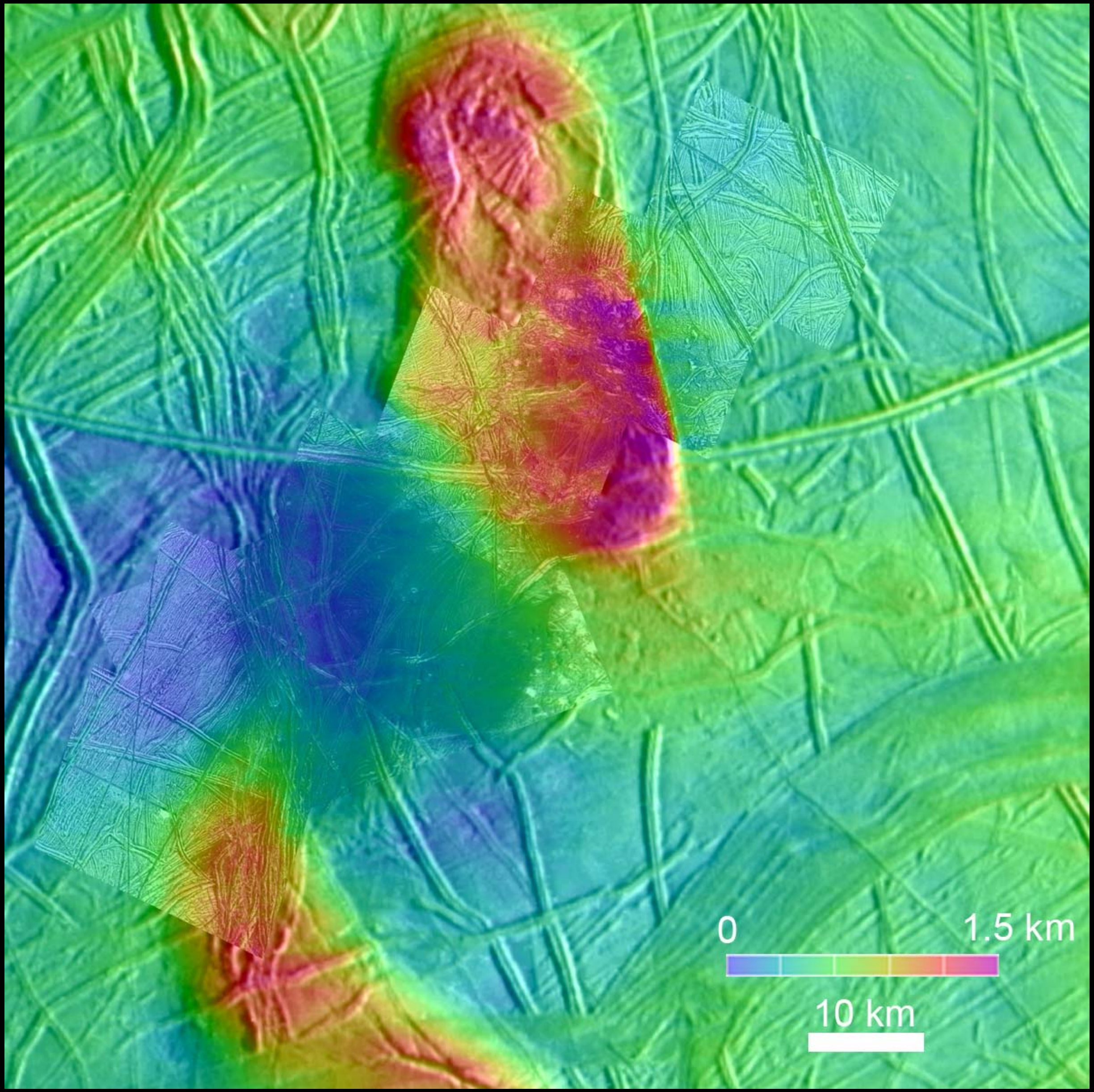
A potential landing site: Castalia Macula



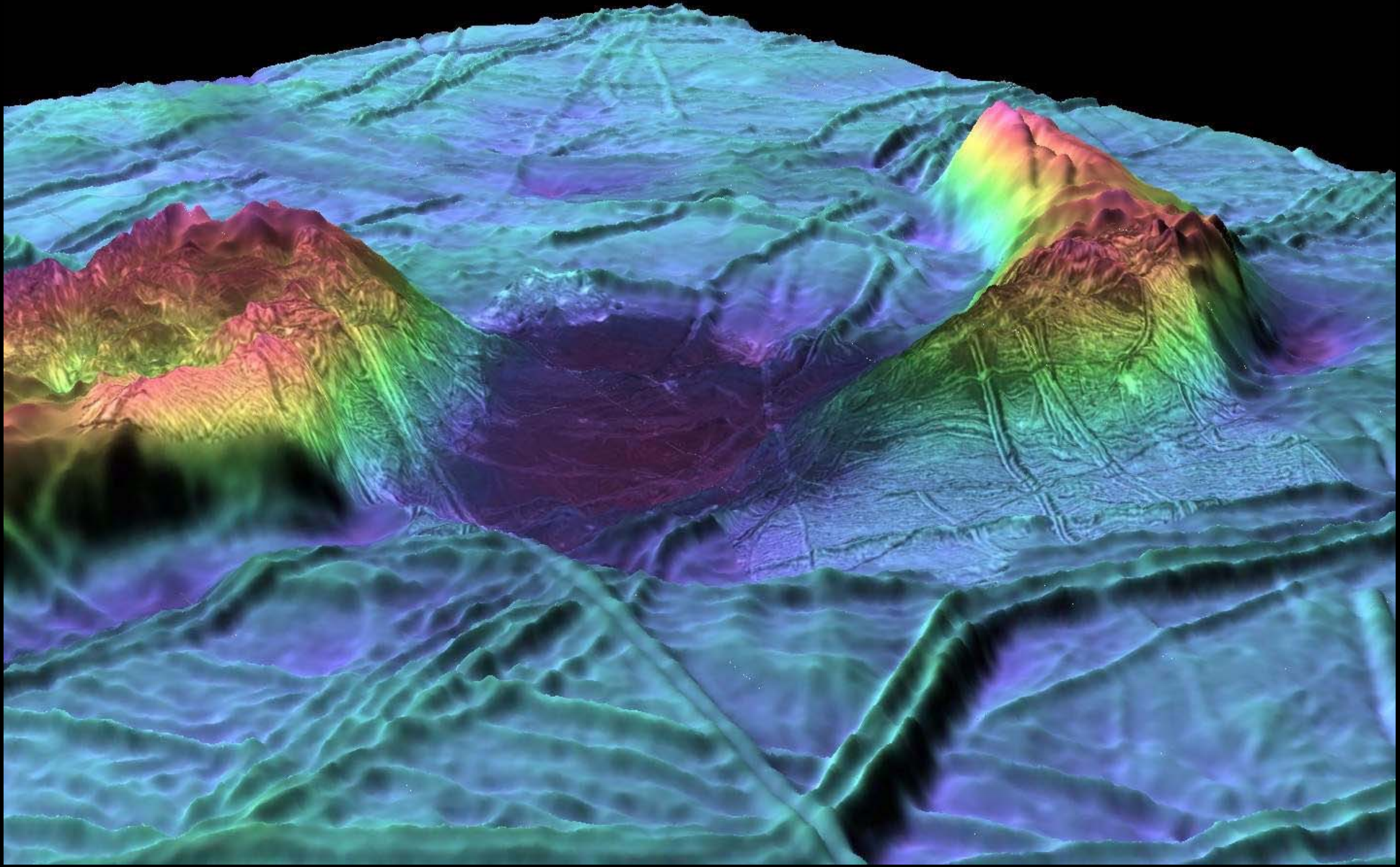
Castalia Macula: Regional setting



Castalia Macula: Topography

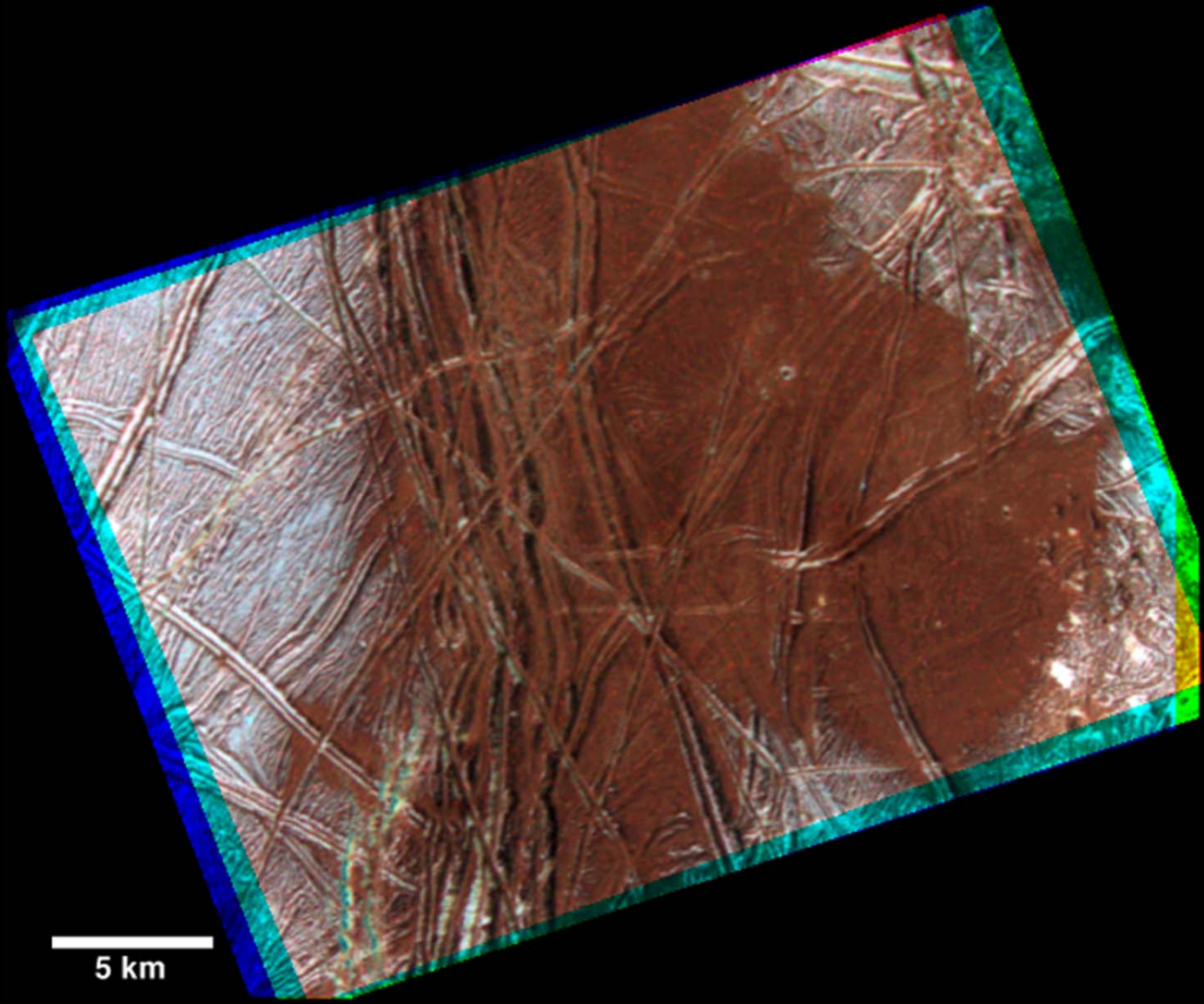


Castalia Macula: View from northwest

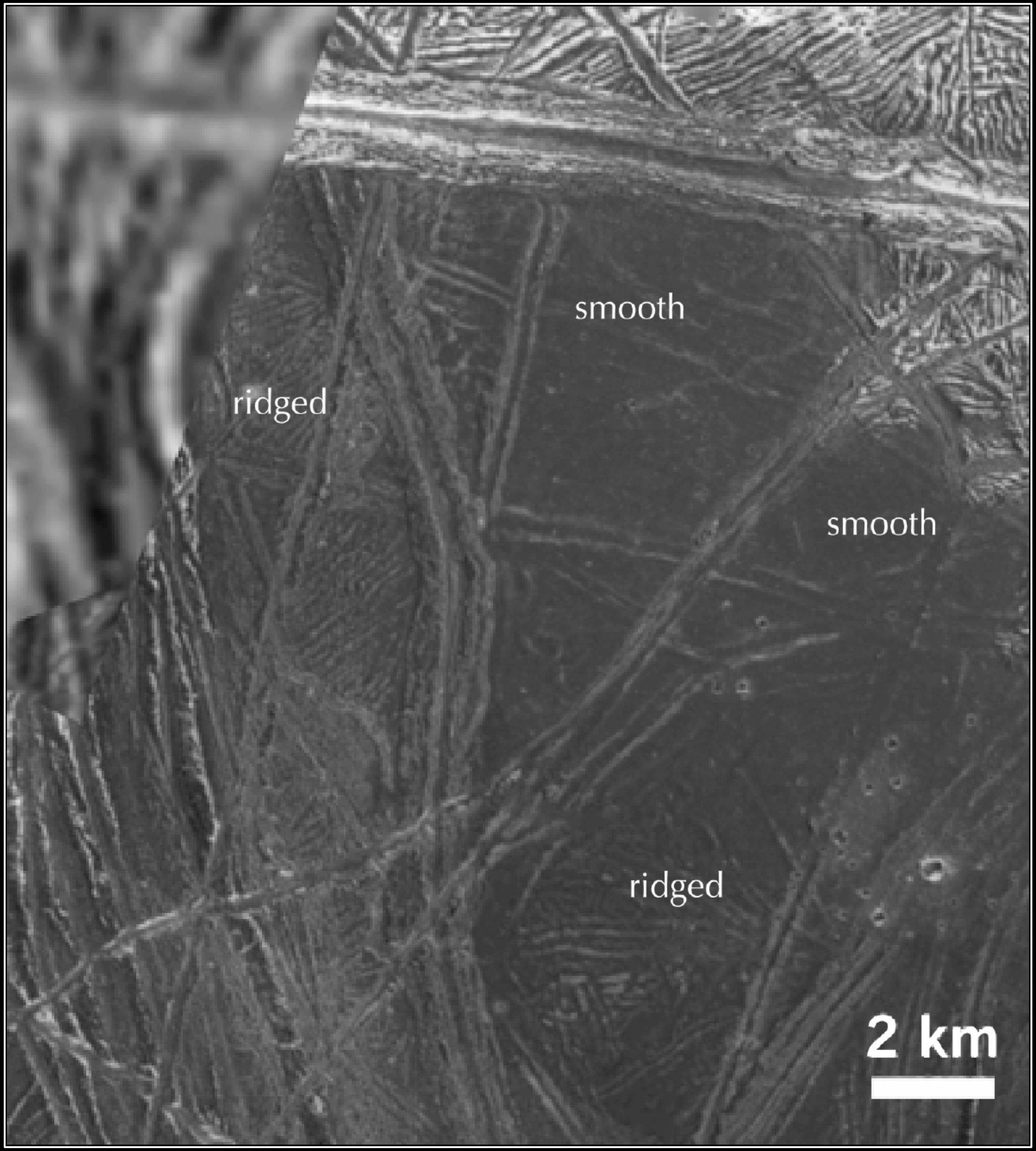


Vertical exaggeration = x 20

Castalia Macula: Color



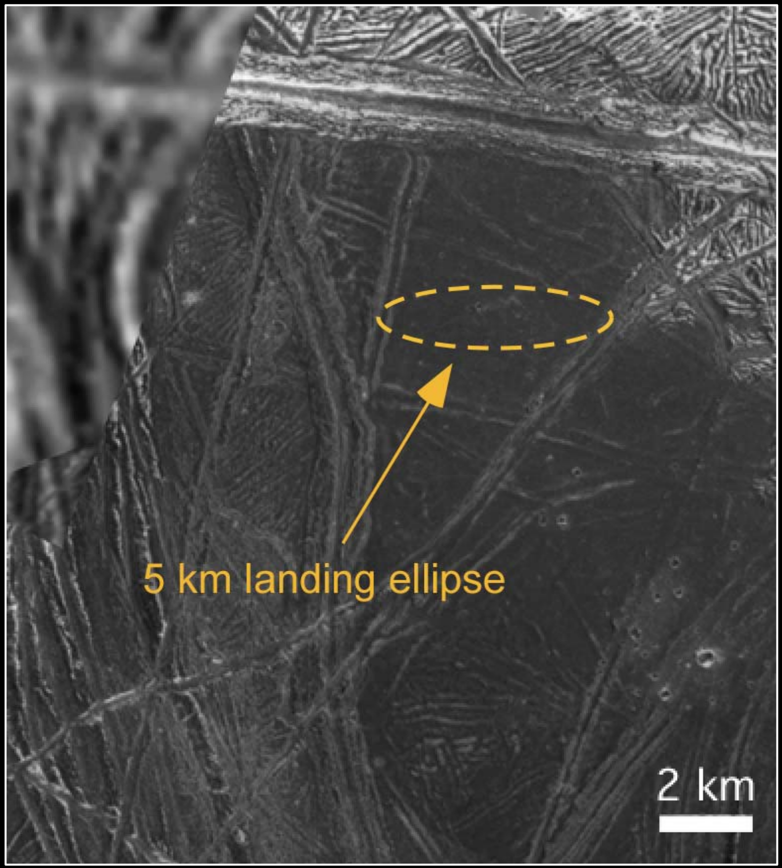
Castalia Macula: Geology

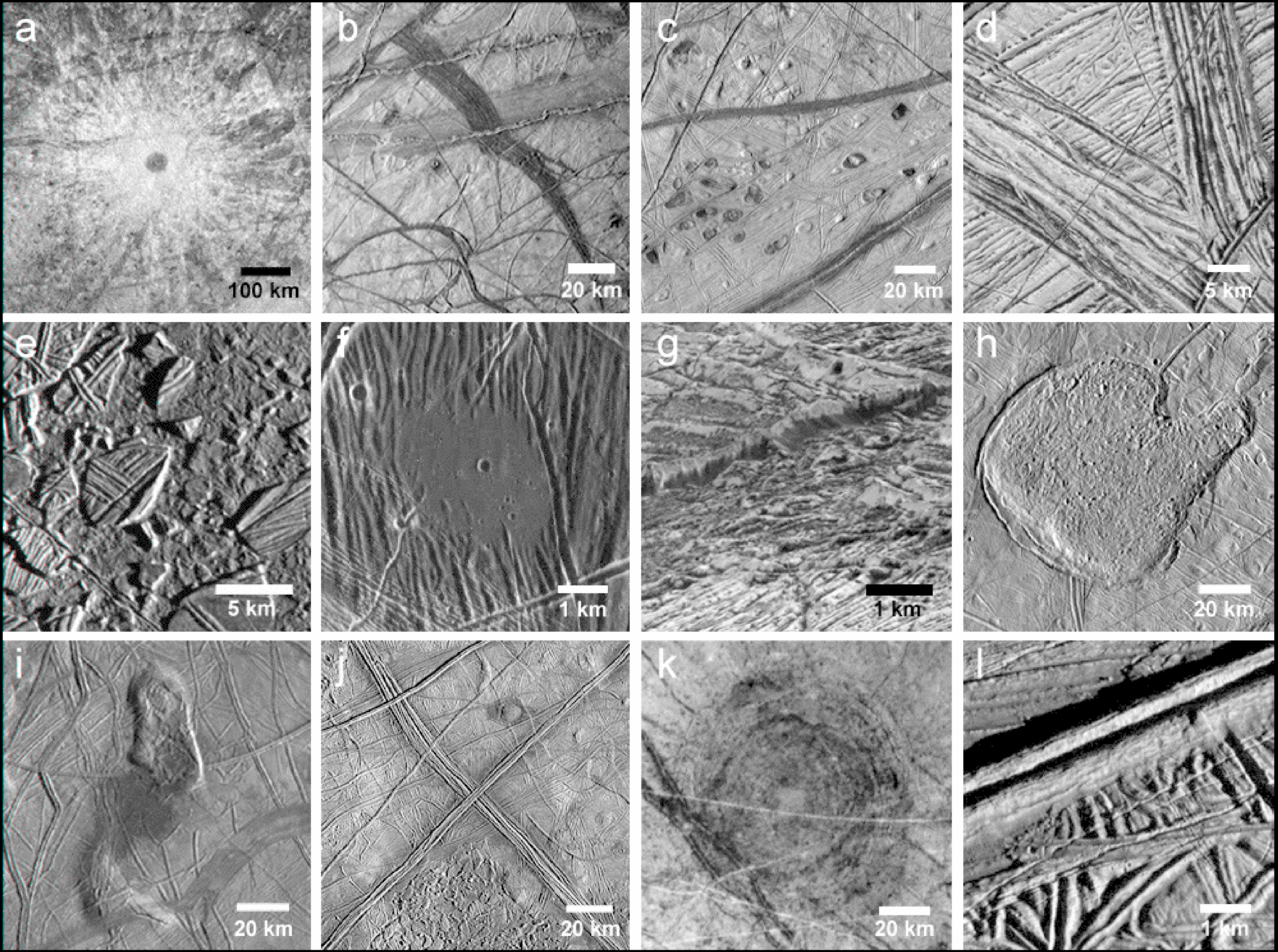


Summary:
Castalia Macula as a potential landing site

Why is Castalia Macula a good candidate?

- Comprehensive data set returned by Galileo spacecraft
- Stratigraphically young
- Low albedo plains are likely material that was brought up from the subsurface
- Relatively smooth and flat area for realistic (?) landing ellipse

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