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Bands on Europa

--- Rifting at Earth's mid-ocean ridges is a good analogy for Europan band formation.

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High-resolution Galileo images of Jupiter's icy moon Europa show linear, curved, and wedge-shaped bands crisscrossing the surface. The bands are one of five primary terrain types previously mapped on Europa; the other types are plains, chaos, ridge, and crater materials [see PSRD article: The Europa Scene in the Voyager-Galileo Era.] Now a team of scientists from the Applied Physics Lab (APL), Brown University, Cornell University, the Nordic Volcanological Institute (Iceland), and the Institute of Planetary Exploration (Germany) have made detailed maps of five distinct bands. Louise Prockter (APL) and her colleagues compare the Europan bands to Earth's mid-ocean ridges. They discuss fast-spreading and slow-spreading models for the Europan bands showing how warm ice may have welled up to the surface through fractures. The team concludes that mid-ocean ridge rifting is a good analogy for Europan band formation, that bands were responsible for hemisphere-wide resurfacing on Europa, and that the style of resurfacing has changed over time.

Reference:

Prockter, L. M., J. W. Head III, R. T. Pappalardo, R. J. Sullivan, A. E. Clifton, B. Giese, R. Wagner, and G. Neukum (2002) Morphology of Europan bands at high resolution: A mid-ocean ridge-type rift mechanism, Journal of Geophysical Research, 107(E5), 10.1029/2000JE001458.

Patterns and structures of the bands

Bands are straight and curved stripes and wedge-shaped zones that cross the surface of Europa. They were first observed as dark lineaments on Europa's anti-Jovian hemisphere in the 1979 Voyager images. Recent high-resolution images (14 to 220 meters/pixel) from the Galileo spacecraft have dramatically increased the amount of detail revealed in the bands. This has led researchers to explore how the bands formed and how they have resurfaced Europa. Louise Prockter and her colleagues looked at a representative collection of bands at different resolutions. They made geological sketch maps and defined geological units based on such physical features as surface shapes, textures, forms, layers, color, and relative brightness. This article summarizes their descriptions and interpretations of the internal patterns and bounding structures for five bands.

Band A

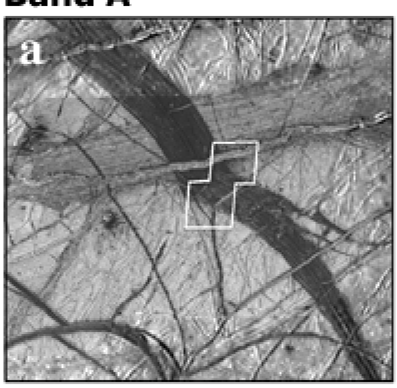
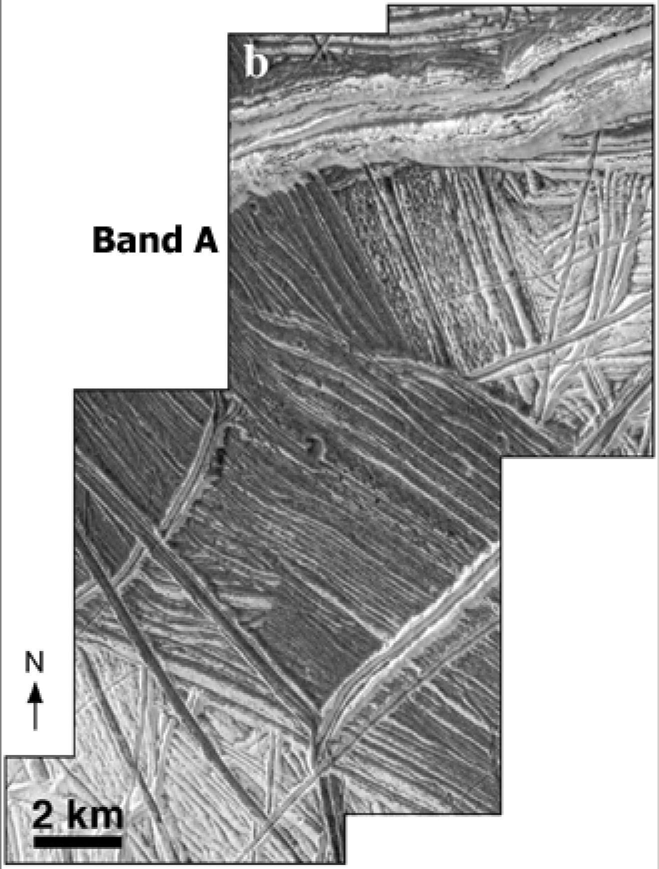


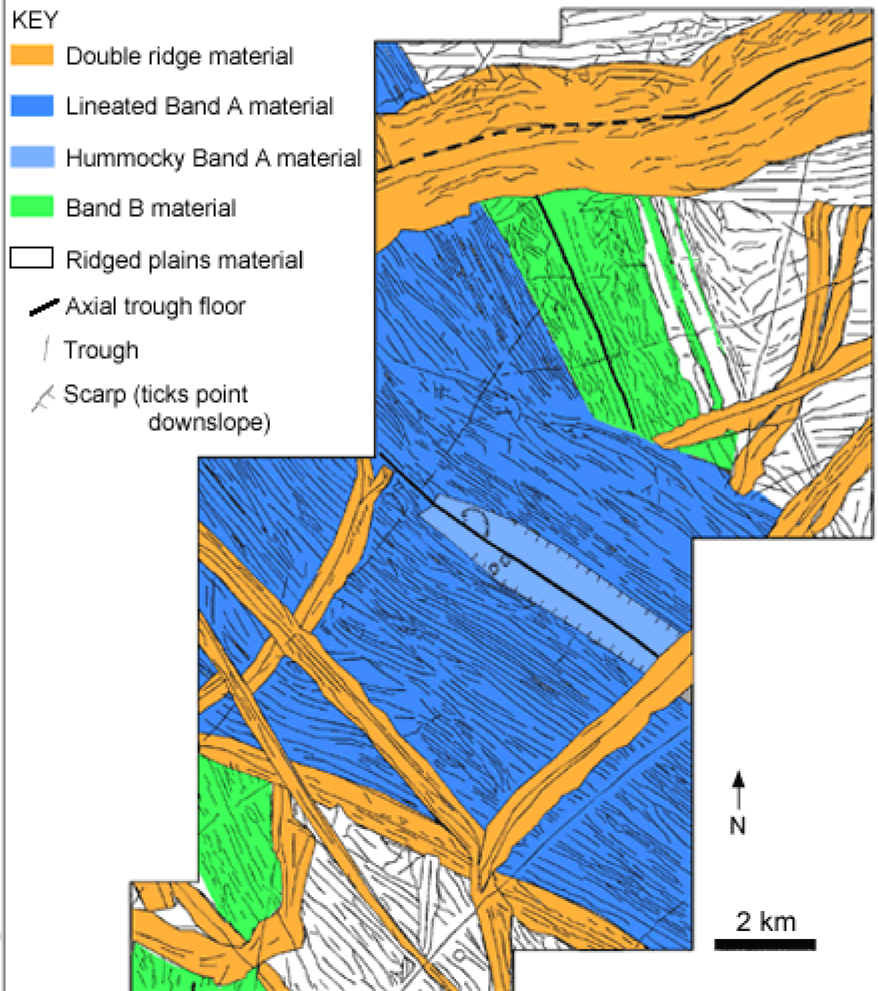
Figure (a) is a context image with white box showing location of Figure (b) and corresponding geological sketch map.
(from Prockter *et al.*, 2002, *JGR*, *107*(E5), 10.1029/2000JE001458)

Band A
This dark, wedge-shaped band (centered at ~17S, 197W) was mapped in detail near an elbow bend using high-resolution (15 to 50 meters/pixel) images. The band has a straight and narrow, V-shaped axial trough shown on the geological map as a heavy black line. Lineations within the band (main dark blue map unit) are generally parallel to this trough and are broadly similar in width and style on either side of the trough. Some areas of the lineated material appear to be sliced by many closely spaced parallel lineaments. Other areas, called lenticulae, have a rougher and chaotic texture created by domes, depressions, and small blocks. Prockter and colleagues found a scarp-bounded depression with a hummocky texture (mounds and rounded hills) that extends about one kilometer to either side of the axial trough (light blue map unit). A double ridge (orange unit) defines the southwestern boundary of Band A with the surrounding plains. Many other double ridges are mapped in this area, but none bound the band's northeast margin. Stereo images show that band A stands 50-100 meters above the surrounding plains.



(from Prockter *et al*., 2002, *JGR*, *107*(E5), 10.1029/2000JE001458)

Band A - Geological sketch map of area



(from Prockter *et al*., 2002, *JGR*, *107*(E5), 10.1029/2000JE001458)

Band B

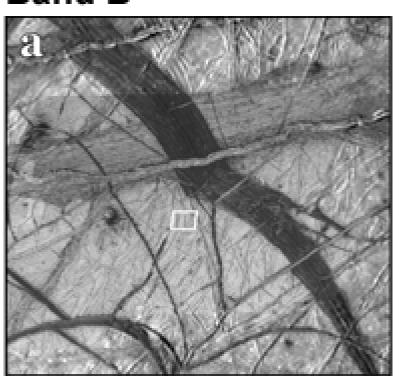
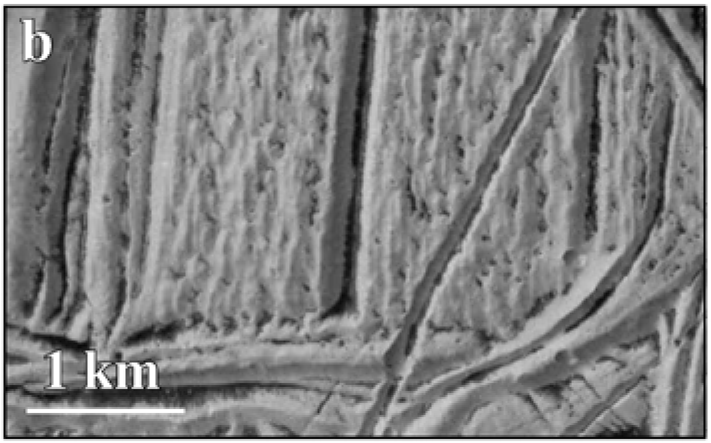


Figure (a) is a context image with white box showing location of Figure (b) and corresponding geological sketch map.
(from Prockter *et al*., 2002, *JGR*, *107*(E5), 10.1029/2000JE001458)

Band B

This narrow (6 km) bright band (at ~16S, 196W) is cut and offset by Band A. In a high-resolution image (14 meters/pixel) Prockter and colleagues found that the band consisted of one surface type which they mapped as hummocky material. Similar to Band A, Band B has a very straight, V-shaped axial trough. A regional slope across the band makes the eastern half over 100 meters higher than the western margin, which is at the same elevation as the surrounding ridged plains. A prominent ridge bounds the western margin of Band B (orange map unit on the left side of the band).

Band B



(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

N

Band B - Geological sketch map of area

KEY
1 km
N
Hummocky Band B material
Double ridge material
Ridged plains material
Crater
Axial trough floor
Trough
Scarp (ticks point downslope)

(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

Band C

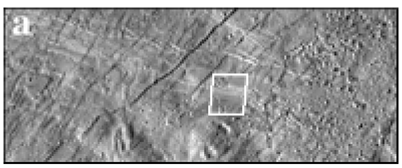
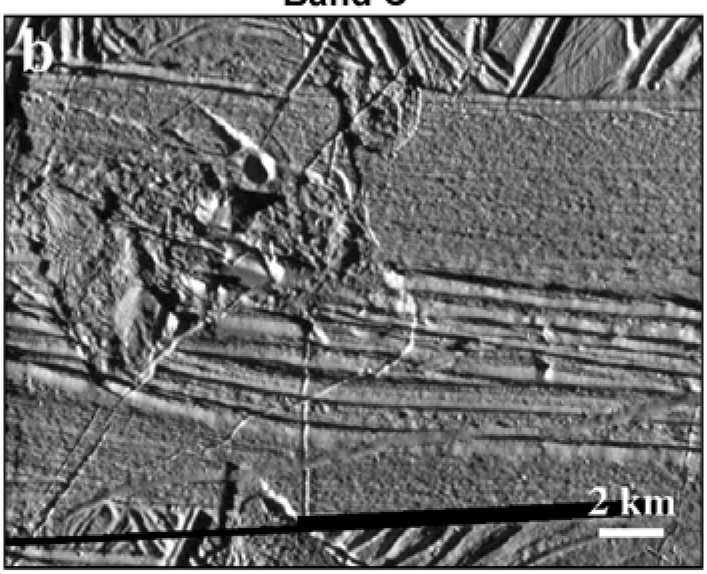


Figure (a) is a context image with white box showing location of Figure (b) and corresponding geological sketch map.
(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

Band C
This wide, gray band (at 35N, 87W) was mapped with a 33 meters/pixel resolution image. The band material is hummocky with lineations parallel to the band margins. Ridges, inferred and mapped as scarps within the band, are about 1 km wide. There is no axial trough. On the left side of the image is an area of chaotic texture, called lenticula, (purple unit on the map) that has disrupted the scarps. A scarp helps to define the band's northern margin, but bounding ridges are absent.

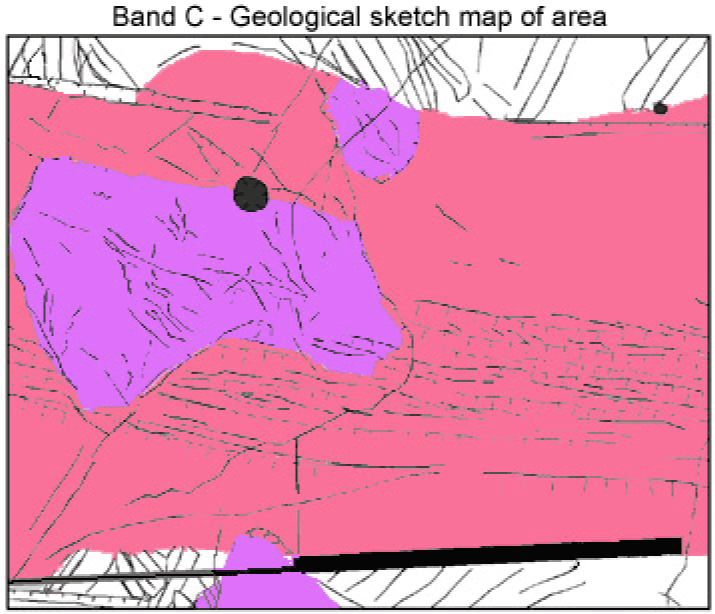
Band C



(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

N

Band C - Geological sketch map of area



KEY
2 km
N
Band C material
Lenticula
Ridged plains material
Crater
Lineament
Scarp (ticks point downslope)

(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

Band D

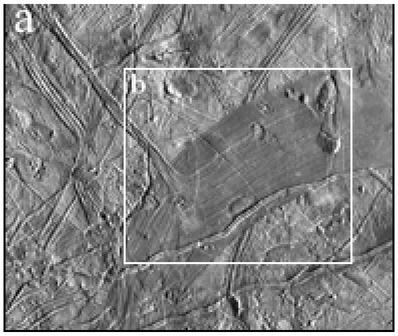
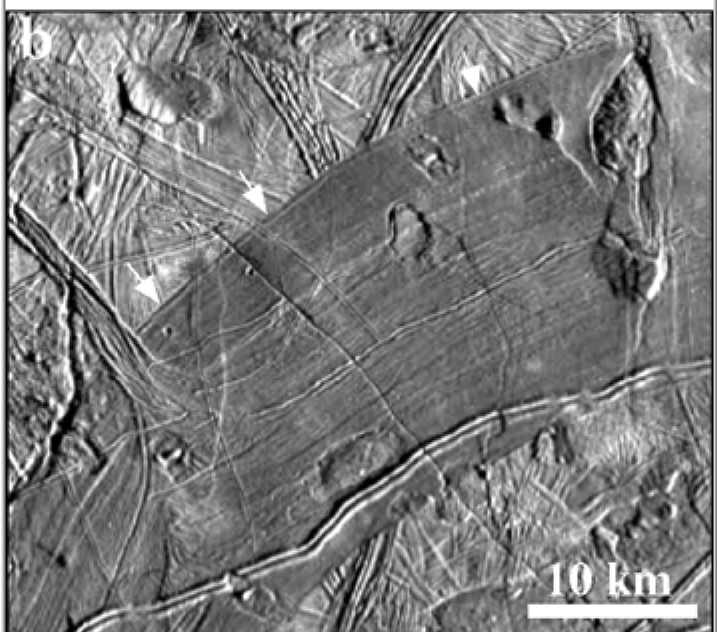


Figure (a) is a context image with white box showing location of Figure (b) and corresponding geological sketch map.
(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

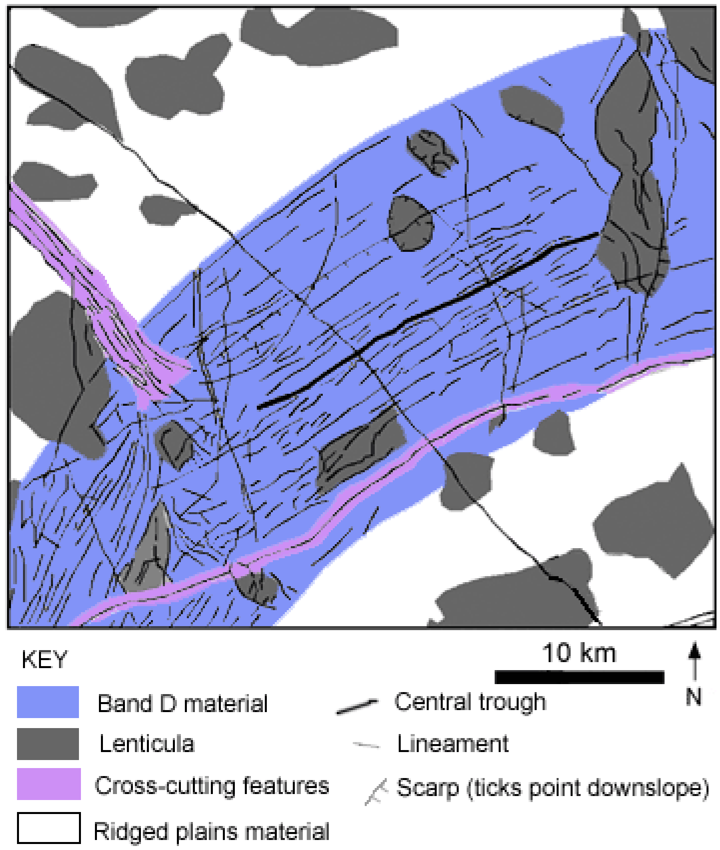
Band D
This gray, sickle-shaped band was mapped at 220 meters/pixel resolution. A central trough is clearly visible despite the much lower resolution than was used to map Bands A and B. While no hummocky material could be resolved in the image, lineaments and lenticulae were mapped. White arrows in Figure B, below, point to the northern border which Prockter and colleagues interpret as one of the preexisting bounding ridges along which Band D formed.

Band D



(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458) N

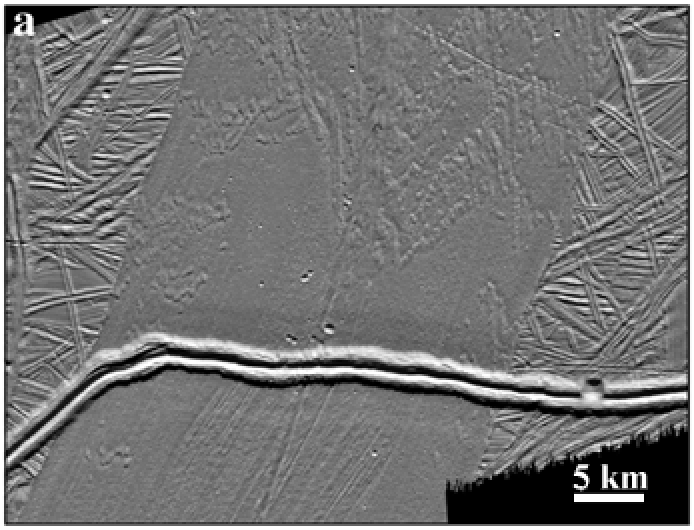
Band D - Geological sketch map of area



(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

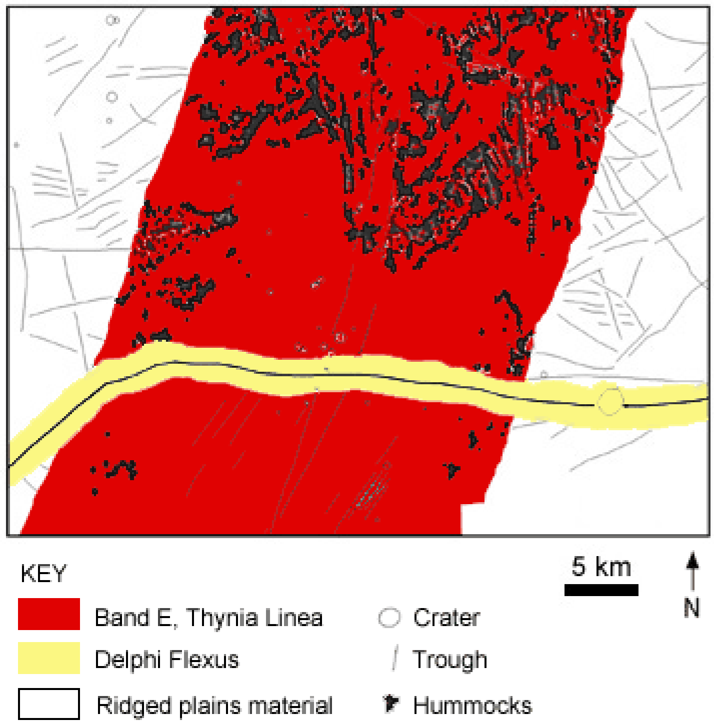
Band E
This large gray band is named Thynia Linea. It is 25 km wide and extends for over 900 km. Using a Galileo image with 38 meters/pixel resolution, the researchers found no axial trough and no bounding ridges. The band has hummocky zones and lineaments. The lineaments are parallel to each other but subparallel to the band margins. The band has an unusual surface texture of hummocks that are typically greater than 500 meters long and arranged in chevron patterns. The double ridge crossing the band is named Delphi Flexus.

Band E



(from Prockter *et al.*, 2002, *JGR*, *107*(E5), 10.1029/2000JE001458)

Band E - Geological sketch map of area



(from Prockter *et al.*, 2002, *JGR*, *107*(E5), 10.1029/2000JE001458)

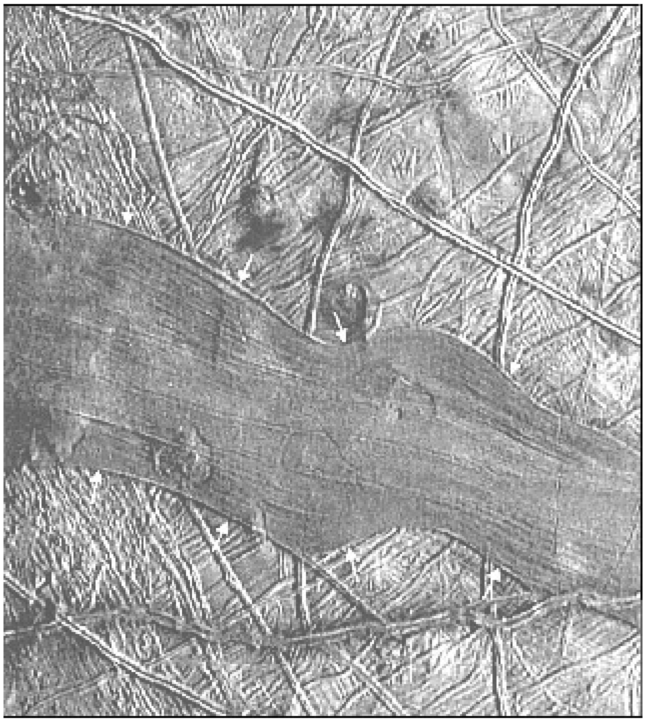
Band formation

The bands examined by Prockter and colleagues showed distinct similarities. All of the bands have linear structures that parallel or nearly parallel the band margins. These lineaments were recognized even in the lower resolution image used to map Band D. If these are ridges and troughs that formed at the band axes, then the researchers say the differences in how the bands look may be due to variations in spreading rate. All the bands mapped at high resolution have hummocky textures. Axial troughs, present in Bands A, B, and D correspond to the center of symmetry in each band and are interpreted as the place where band material welled up and spread out. These similarities suggest that the bands have a common mode of formation.

Prockter and colleagues propose that Europan bands initiated along segments of one or more preexisting double ridges. The central troughs of these double ridges were zones of weakness where lithospheric plates fractured and separated allowing ice to move up and spread out. The researchers think bands formed in discrete, and probably short-lived, episodes of upwelling of convecting warm ice in these regions of brittle and fractured thin lithosphere. The band materials also commonly developed fractures or tilted fault blocks.

Current hypotheses for crustal formation on Europa generally assume that a liquid water ocean exists below a relatively young, icy shell. Based on their geological mapping and observations of the high-standing topography of the bands, Prockter and colleagues conclude that the material that formed the Europan bands was compositionally or thermally buoyant ice, rather than liquid water. Water would have left overflow features, which the researchers looked for but did not find, even when a band lacked bounding ridges.

The Galileo image below shows what the surface of Europa looks like now. To get an idea of what the preexisting surface looked like and how the dark band may have formed, just put your cursor on the "Start rifting" button.



(from Prockter *et al.*, 2002, *JGR,* 107(E5), 10.1029/2000JE001458)

Set your cursor over the button to view a simple animation of the rifting and opening of Band D.

Ridges in the preexisting plains that end abruptly at the margins of Band D match up again when the band margins are reconnected in this animation. However, in three other cases (Bands A, C, and E), the researchers found some lateral offset along the bands.

Terrestrial counterparts: mid-ocean ridges

What is the process of band formation that has helped shape the icy surface of Europa? Prockter and coauthors say that the so-called pull-apart bands correspond to places of separation and spreading of Europa's icy shell in a style comparable to rifting at Earth's mid-ocean ridges. On Earth, rifting is the initial separation of the crust. The basic stages of rifting and sea-floor spreading on Earth can be summarized, for example by Sommerfield:

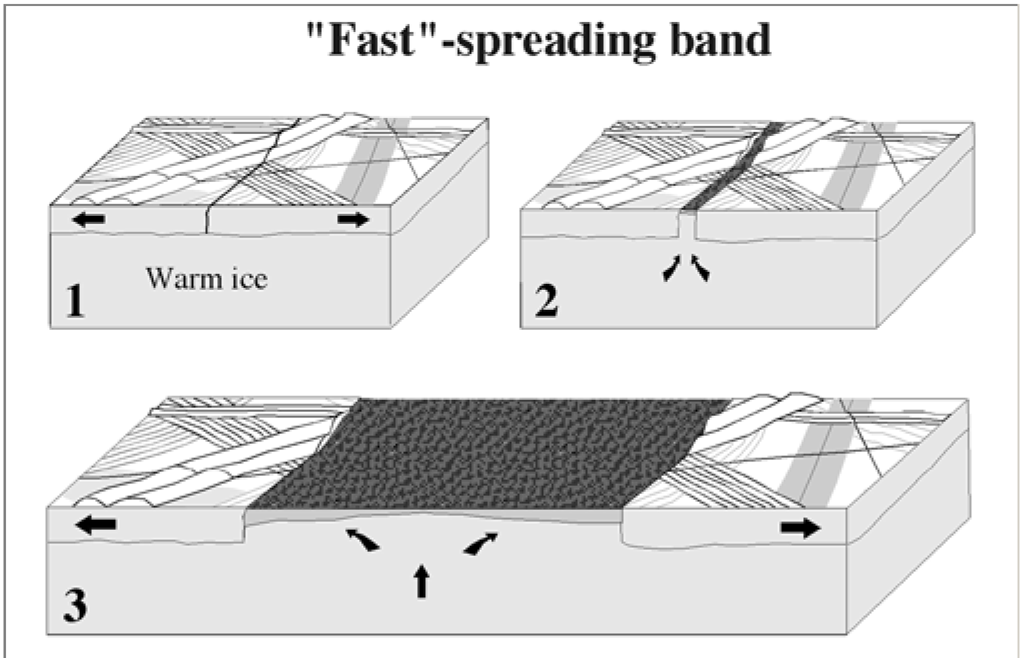
- Heat source beneath rift axis warps the crust
- A depression is formed in the crust, followed by subsidence and splitting to create vertical fractures
- A "rift block" is created
- Doming and extension (pulling apart) occur to form a rift basin
- Magma wells up through the fractures to the crust and spreading begins
- A fast spreading ridge (such as the Earth's fastest: East Pacific Rise) has a greater volume and lower topographic expression than a slow spreading ridge (such as the Mid Atlantic Ridge).

When Prockter and coauthors compared Europan bands to terrestrial mid-ocean ridges, they noted similar features such as: upwelling and emplacement of new lithospheric material, broadly symmetrical spreading, central axial troughs, hummocks and hills, some oblique opening, and relatively higher topography than the surroundings. The main difference they found, in addition to the fact that on Earth the new material is volcanic rock and on Europa it is ice, is the lack of evidence of subduction on Europa. Subduction is a driving mechanism of rifting at Earth's mid-ocean ridges. On Europa, as noted in the previous section, the driving mechanism may simply be the convection and upwelling of warm ice.

If a terrestrial seafloor-spreading model is applicable to Europan bands, then the researchers speculate that the differences they see in the bands are due to the relative rate of spreading of each band. In their fast-spreading model, the researchers illustrate three main steps of formation of bands on Europa (see diagram below).

1. The surface is in tension and fractures.
2. Warm ice wells up, but spreading is fast enough that no brittle shell forms on top.
3. The brittle surface layer is thin and weak and has subdued topography. Band material has a uniform texture of small hummocks. There is no axial trough.

Bands C and E, which lack prominent axial troughs and have uniformly small hummocks, may have opened relatively rapidly.

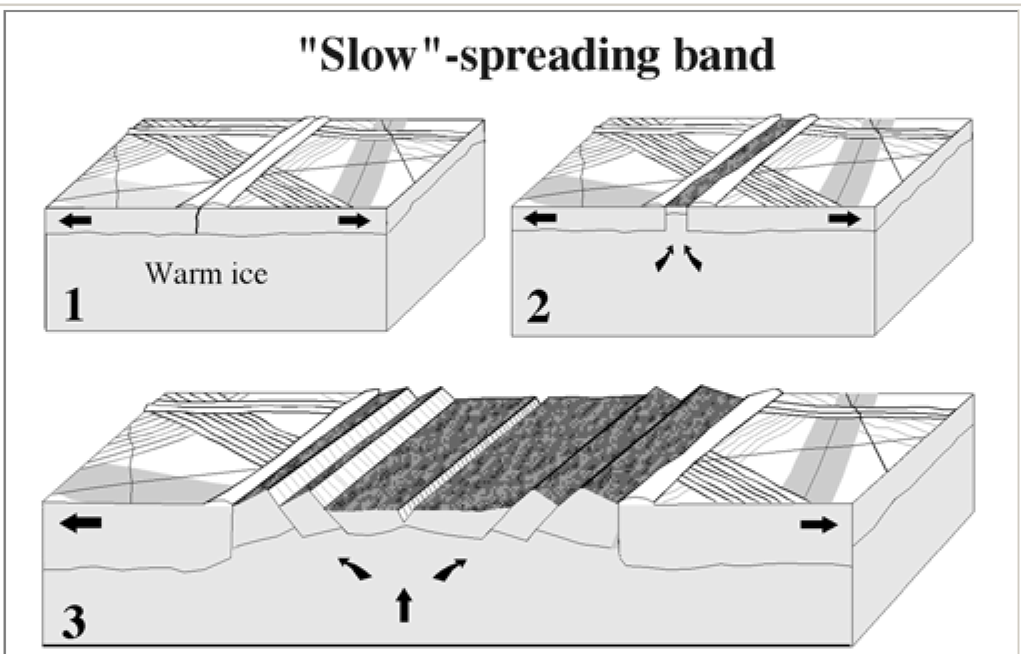


(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

Prockter and colleagues' slow-spreading model has a different outcome (see diagram below).

1. The surface is fractured or a preexisting weakness is exploited.
2. Warm ice wells up. Slow spreading results in significant thickening of the brittle layer.
3. The brittle layer is thick enough to fracture and support significant topography. New material may pile up, forming hummocks. There is a distinct axial trough.

Bands A and B may have opened relatively slowly.



(from Prockter *et al.*, 2002, *JGR, 107*(E5), 10.1029/2000JE001458)

And then there was a change on Europa

Bands may have contributed significantly to the resurfacing of Europa. In fact, in a region near the anti-Jovian point, the researchers found that bands make up nearly 60% of the ridged plains. But Prockter and her colleagues also found that lenticulae (the areas of chaotic texture formed by domes, depressions, and blocks) disrupt band materials. None of the areas they looked at show lenticulae split or separated by any of the bands. It follows that lenticulae formed after the bands, and may turn out to be additional surface expressions of warm ice convection and eruption.

Prockter and colleagues argue that this change from bands to lenticulae implies the style of resurfacing on Europa has changed over time, which they interpret as a consequence of a thickening of Europa's ice shell. This interpretation is consistent with earlier proposals that Europa's lithosphere thickened with time because of the progressive freezing of a global ocean. How long band formation lasted, how old the surfaces are on Europa, how deep the ice is, exactly what's under the ice, and details about a convecting ice layer or enigmatic hidden ocean are but some of the intriguing questions challenging planetary scientists today. With the April, 2002 cancellation of the original Europa Orbiter mission, scientists now are proposing the Europa Geophysical Explorer (which is in the preliminary mission concept definition phase) to learn more about the icy moon and its geologic, or potential biologic, history.

Additional Resources

Europa Geophysical Explorer, in Preliminary Mission Concepts from NASA's Office of Space Science.

Europa images from the Galileo Mission.

Europan lenticulae image from NASA Planetary Photojournal, press release from Galileo News at Jet Propulsion Lab.

Martel, L. "The Europa Scene in the Voyager-Galileo Era." *PSR Discoveries.* Feb. 2001. <http://www.psrd.hawaii.edu/Feb01/EuropaGeology.html>.

Prockter, L. M., J. W. Head III, R. T. Pappalardo, R. J. Sullivan, A. E. Clifton, B. Giese, R. Wagner, and G. Neukum (2002) Morphology of Europan bands at high resolution: A mid-ocean ridge-type rift mechanism, *Journal of Geophysical Research,* 107(E5), 10.1029/2000JE001458.

Prockter, L. M., and R. T. Pappalardo (2000) Folds on Europa: Implications for crustal cycling and accommodation of extension, *Science,* v. 289, p. 941-943.

Sommerfield, C., Introduction to Ocean Science MAST 482, Lecture 5 , University of Delaware, Graduate College of Marine Studies.

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