

## Impact Generated Transitions from Double Ridge to Band Production on Europa

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 Comments: 3 Figures  
 Journal Reference: Paper 2 of Vol 2 of CD ebook ISBN 0-646-40916-6  
 at [www.nodrift.com](http://www.nodrift.com) since 21 Dec 04

**Abstract:** Dual modes of a tidal mechanism produce Europa's ubiquitous double ridges, bands, and intermediate forms. Transitions to band production are triggered by impact tectonogenetic, subcrustal ocean heating episodes, most likely separated by 1-100 Ma quiet periods. Impact melt-freshened ocean surface at tidal cracks freezes into brittle new ice compared to the tough new ice of saltier pre-impact ocean. This brittle new ice is simply squashed, frozen, broken into half-ridge abutments by tidal movements. A dilating succession of such abutments becomes a band, occupying ocean space created by impact melt. If the impact-melted ocean providing band space contains many icebergs, these pack tighter together, become chaotic terrain. Transition to double ridge production occurs when colder, saltier seawater ice subsequently produced by quiet period ocean mixing causes tidal movements to "roll" the tougher new ice upwards.

**Keywords:** Europa, Gannymede, Callisto, Earth, crust, surface layer, space exploration, human habitation

### Introduction

I had looked to Europa, after finishing the other, numbered Volumes of this CD ebook, with the intention of doing only the preceding, long-overdue paper as quickly as possible.

This and the next paper are "spin-off"; they happened only because I perceived more than I had been looking for in JPL (1999) images.

#### GREENBERG ET AL MODEL

In Tufts et al's (1998) explanation of the double ridge production model of Greenberg et al (1998a), Class 2 [double ridge] ridges develop if "some of the ice that forms during the tensional tidal phase gets stuck in a central crack. This accumulation . . . . in effect, pushes the adjacent lithospheric blocks apart. . . . the crack wall in Class 2 ridges experiences an outward pushing force in the [tidal] compressional phase . . . , successive paired ridges accumulate in the widening gap between initial ridge-pairs, if any. Tidal compression associated with this forced separation of opposing plates shoves the new interior material upwards. . . . , **a groove develops at the active crack. This groove may be maintained in the same relative location by compressional consolidation of the crack walls.** The hummocky surface of Class 2 ridges may result from crushing in the compressional phase." [my emphasis]

The emphasised words were presumably included by Tufts et al because of a need to accommodate their reconstruction of double ridge dilation of the preceding page:

"Two prominent internal dark lines can be brought together . . . , demonstrating that [they] may mark the two halves of an original double ridge. The reconstruction was achieved with few gaps or overlaps and significantly improved the alignment of at least ten older lineaments, including two small cracks at the western margin of the image . . . . The reconstruction demonstrates that this Class 2 ridge opened normal to its trend and is therefore dilational."

#### DEFICIENCIES

I propose that this reconciliation of the Greenberg et al model is unconvincing, deficient for several reasons:

- It has not been indicated how "compressional consolidation"/ "crushing in the compressional phase" have been able to raise the larger of these well-formed structures;

- It is extremely unlikely that “tidal compression” can provide sufficient “compressional consolidation”/ “crushing in the compressional phase” to raise such large structures as double ridges, whatever intervening mechanism;
- It has not been indicated how any such mechanism might be coupled to “the widening gap between initial ridge-pairs” to produce the observed “same relative location . . . . of the crack walls”, something which is unlikely to happen randomly.

Researchers in the field would generally agree with Tufts et al’s (1998) explanation of how “lithospheric dilation on Europa has occurred at Class 2 [double ridge] ridges and at bands, on a global scale. . . . Some lineaments combine characteristics of both Class 2 ridges and bands. The character of the Class 2 ridges, bands, and the intermediate forms suggests that they all are dilational gaps in the European lithosphere. . . .”

“It has been suggested that bands represent the last stage in an evolutionary sequence in which doublet and complex ridges [our double ridges and intermediate forms] are intermediate steps in the process (Greeley et al 2000).”

Tufts et al (1998) continued: “Variation in morphology among dilational lineaments depends upon the degree to which pulling-apart counteracts tidal compression.”

“Dilational lineaments represent an important agent of resurfacing on Europa . . . . Lateral displacements . . . imply that as lithospheric blocks separate and create new surface area, pre-existing surface must be consumed elsewhere.” (Tufts et al 1998). Two ways in which this might happen are suggested:

- “. . . . melting-through of lithosphere at various times and places, creating chaotic terrain.”
- “Dilation on some bands may accommodate strike-slip on faults to which they are linked.”

#### IMPACT GENESIS

No mention is made by any of these authors, or others in the field that I can find, of the possibility that impacts produced the transitions. An “evolutionary sequence” seems to be as near as anyone gets to mentioning impact.

As explained in paper 1, identical dimensional clustering of serms, into 20, 16, 13, 11, 10, . . . pixel groups, in both Libya Lineal and Astypalaea Lineal bands on Europa indicates an 840m ice thickness of both bands when they were impacted, and that the Libya Lineal-genetic impact probably happened at the same time as the Astypalaea Lineal impacts.

The identical ice thicknesses indicated for both bands, unlikely to be a random coincidence, is consistent with their much earlier co-impact geneses also, as explained below.

#### “SALT ICECREAM” MODEL

My proposed dual-mode mechanism combines generally understood background processes: tidal tectonics, dilations, strike-slip (i.e. lateral shear) displacements, and so on, with fracture-melt effects of huge impact.

Transitions to band production (Fig 1), are triggered by impact tectonogenetic, subcrustal ocean heating episodes, most likely separated by 1-100 Ma quiet periods.

Transition to double ridge production (Fig 2), is triggered after a quiet period of cold, relatively stable conditions. Intermediate forms are produced by intermediate conditions.

Super huge impacts separated by 100s-1000s Ma quiet periods would most likely have involved complete surface renewal, as explained in the next paper.

Figs 1 & 2 are schematic, simplified. Full “flowering” of my “icecream spirals”, Fig 2, may involve very large numbers of tidal movements to produce the largest examples.

This would not be a problem on Europa because there is no weather there to interfere with such a process.

#### COMPARISON WITH GREENBERG ET AL MODEL

Consistent with dilational reconstructions of double ridges and bands, Tufts et al’s (1998) reconstructions and so on, my model has none of the listed inadequacies of the Greenberg et al model.

In its double ridge building mode (Fig 2), the “accumulation” . . . “of the ice that forms during the tensional tidal phase” is curved upwards, moves upwards, eventually backwards, completely beyond the central crack.

This contrasts with the accumulation’s getting “stuck in a central crack [and pushing] . . . the adjacent lithospheric blocks apart” of the Greenberg et al model.

Only in my model’s subsequent band-building mode (Fig 1) do “. . . successive paired ridges accumulate in the widening gap between initial ridge-pairs, if any.” (Tufts et al 1998)

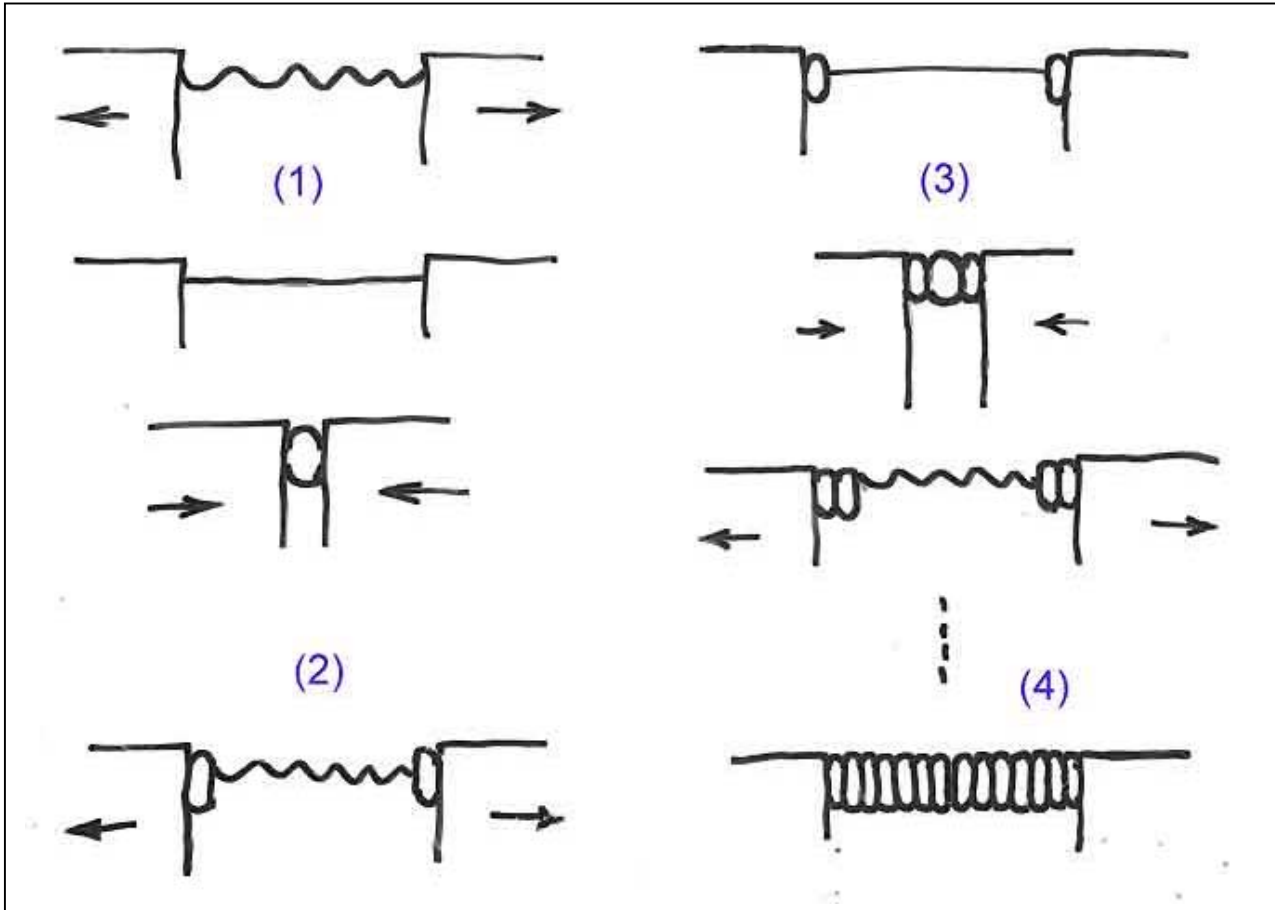


Fig 1: Band Genesis

“SOFT SERVE” MODE, FIG 1

Both Figures are schematic. When impact tectonogenesis sufficiently warms the ocean, the partially melted and shattered icy crust forms a layer of relatively fresh melt water, sometimes containing icebergs.

The effect is the same as what happens in the Antarctic pack ice during the summer thaw. When saltwater ice freezes, it leaves brine behind. The new ice is much less salty than the ocean it freezes from.

If this post-impact scenario happens soon enough after a tidal crack had refrozen after building a double ridge, Fig 2, such double ridge cracks re-open, begin producing a band:

1. Impact-freshened ocean surface water in the tidal rift gap freezes into brittle new ice between tides, compared to the tougher, saltier new ice of the pre-impact ocean.
2. This more brittle ice is squashed, broken into half-ridge abutments at each tide.
3. A dilating succession of such abutments becomes a band occupying ocean space created by impact melt, generally elsewhere.
4. A quasi-symmetrical sequence of ridges, comprising ridged half-bands on either side of the gap is thus produced.

5. If the impact melted ocean providing band space contains many icebergs, these are packed tighter together, become frozen into "chaotic terrain".

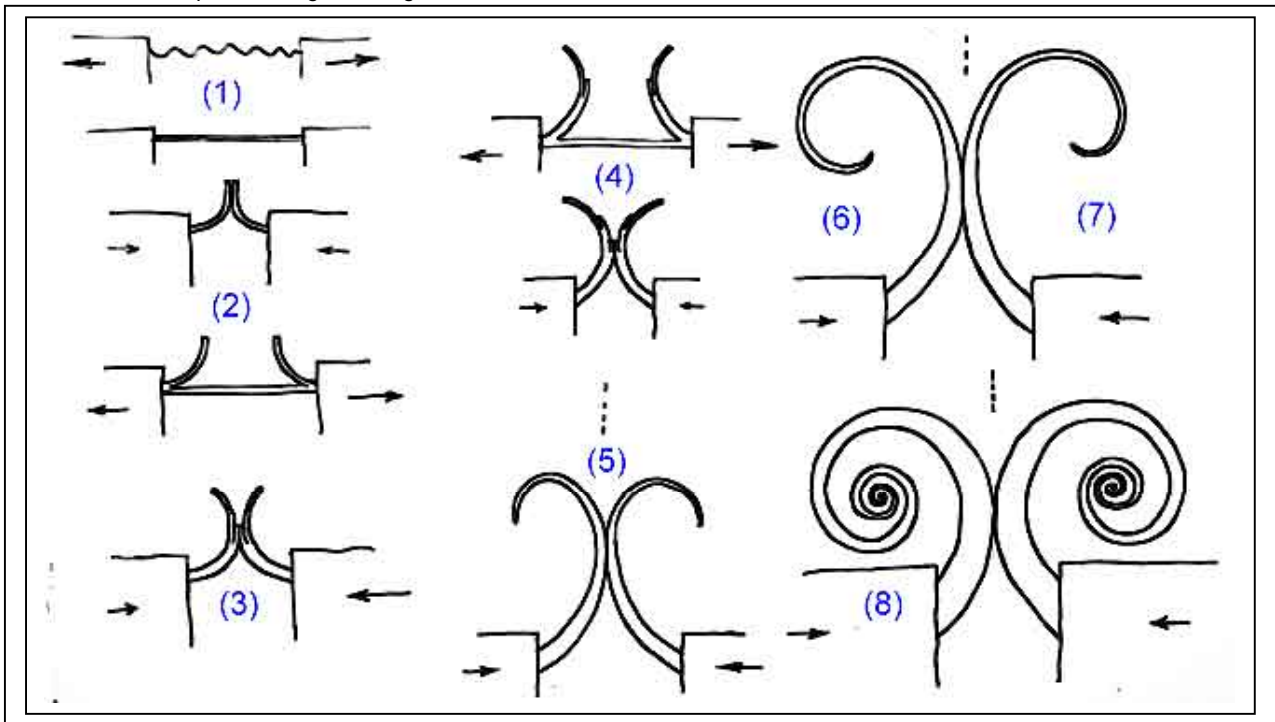


Fig 2: Double Ridge Genesis

"HARD SERVE" MODE, FIG 2

Transition to double ridge production is triggered by subsequent quiet-period ocean mixing.

1. Colder, saltier seawater ice bridges freeze harder and tougher than "Soft Serve" mode ice bridges, resist being squashed.
2. Upper sides of these bridges exposed to a vacuum, are toughest, so tidal convergence bends them upwards, where they break along their centres. Both halves continue to curl upwards.
3. The effect is a "flowering" process: Petals projecting upwards,
4. Eventually backwards,
5. Downwards.
6. Successive tidal convergences continue the curling process while thickening the stems.
7. New increments, half-bridges are successively shorter also, because the tidal rift gap is closed by the thickening stems. In this mode, tidal movement is increasingly restricted. No space to be grown into has been opened up by impact, as in the "Soft Serve" mode
8. Tidal forces are fairly constant, so the thicker and shorter the stems, the less they bend at each tide. The end result must therefore tend to be spiral-shaped petals consistent with "double ridge" production.

How far spiralling continues probably depends mostly on time and overall scale, which probably increases with cooling and increasing thickness of crustal ice.

The cumulative process presumably continues until the bond between the two stems becomes relatively deep and strong compared to the bond of any regional successor, proto-tide crack.

A closed gap would generally continue to thicken. Subsequent impact tectonogenesis may sufficiently warm the ocean to re-open this or other gap, and produce a transition to band production, Fig 1.

**MULTI-SCALE:** The robust simplicity of the Hard Serve mechanism explains the multi-scale ubiquity of double ridges. Tubular cross-section is frequent only amongst largest double ridges, consistent with most recent genesis.

The narrower ridges are thus evidently generally older, produced upon a warmer, less salty quiet-period ocean, sooner after super huge impact renewal of European crust, 2.3.

New ice bridges formed sooner after crustal renewal were thinner and softer than they become, as the evaporating, increasingly concentrated, salty ocean cooled.

Such thinner, softer early ice would have curled into tighter spirals, producing the smaller double ridges, close to the petal curling that can be seen happening in renewed Antarctic pack ice:

Antarctic petal examples, only 30 cm across, HOW DISCOVERY HAPPENED Points 2-5 below, form from ice bridges which are only ~1 cm thick, between 1-metre thick crust.

Larger European petals have presumably been produced from thicker new ice bridges between colder, thicker ice, over larger numbers of tidal movements.

## **DOUBLE RIDGE GENESIS**

It is generally understood that tidal stress produced Europa's ubiquitous tidal cracks, probably including its strangely ubiquitous, multi-directional, double ridges (Greenberg et al 2000).

Prockter and Pappalardo (2000) refer to these double ridges as "troughs", Greenberg et al (2000) as Class 2 or "double ridges", European lineaments generally as "complexes of ridge systems, usually parallel or braided sets of double ridges". . . . "Much of the [European] surface is covered with densely packed crisscrossing sets of double ridges".

Even bands, and "complexes of ridge systems" generally show tide-crack-symmetric ridges along at least one side, so whatever mechanism is producing them must be extremely robust.

### **DOUBLE RIDGES AS "ICECREAM SPIRALS", "PETALS"**

The ubiquity of the double ridges implies that they are extremely durable, proves that European surface ice is extremely hard and tough. This idea is corroborated by Points 2-5 below.

Salty ice at the extremely cold European surface atop ~ 1 km-thick ice may well be hard and tough enough to produce more coherent, much larger "petals" than are produced in Antarctica . . . :

Possibly up to 300-times-larger "petals", spirals, possibly strengthened by fibrous lifeforms, "salt icecream spirals" alongside repeated tidal convergences, as shown in Fig 2.

Such spiral structures would subsequently have relaxed onto the crust, subsided relatively quickly compared to more substantial forms of ridges, into flatter cross-sections.

Subsidence/relaxation would make such double ridges less dependent on support from the stem/bud, increasingly like the ridges we actually see on Europa.

### **"FLOWERING" MECHANISM**

Exposed water freezes first at the edges of a tidal gap. The centre of the new ice bridge is where the ice is thinnest, so bending happens here.

If the new ice is hard and tough enough, it curls upwards, as earlier explained. Eventually, the "budding stems" are in the water, cylindrical "petals" in the air.

The effect is a double ridge "rolling" process. All but the thickening stem of each petal is thrust high above. The robust simplicity of the mechanism explains the ubiquity of European double ridges.

### **PETAL IRREGULARITIES**

The Antarctic "petals" break off before curling backwards very far, to form roughly symmetrical ridges comprising a mixture of still-standing and fallen petals.

Antarctic output is relatively inconspicuous because Earth's seawater ice is relatively brittle, inviscid, warm and fragile, only ever capable of producing small, fragile "petals", and these only prior to the summer thaw.

European ridge morphologies are consistent with having had the same cylindrically-curved, symmetry of the Antarctic "petals", only on a much larger scale, more durably with fewer irregularities, longitudinal and transverse faultlines.

#### NULL FORMS

Extensive, gradually curved faultlines without any suggestion of surrounding petals, are evidently non-opening-and-closing tide cracks.

My dual-mode mechanism has presumably not been effective along these cracks because tides (or various waves) have not been opening and closing them enough, possibly over very long time scales in some cases.

This may be because of incomplete fractures, or complete fractures subject to sub-threshold tidal forces, because of angles, tidal variations and so on.

#### **“HARD SERVE” MODE EVIDENCE**

##### CYLINDRICAL FORMS

The strongest evidence is the roughly cylindrical forms of many of the larger, presumably most recent double ridges, especially along inner, crack-adjacent walls, consistent with my model.

##### TEXTURE

The next strongest evidence is the layered, “baguette/flaky pastry” texture of the larger, presumably most recent double ridges, consistent with spiral petal degradation, relaxation.

Flaky layering is evident as shallow depressions, consistent with part of a layer or flake collapsing onto the next intact layer or flake below it

Flaky layering is also evident as narrow ridges, as within the crack of the double ridge on the LHS of 46666 0113r, and along the RHS outer wall of the double ridge at the LHS of 46 666 0200r (JPL 1999).

“Flaky pastry” texture is evident within half the images of Europa I have seen, most strongly on the LHS of 46 666 9939r, upper RHS of 46 666 0113r, LHS of 46 666 0200r.

##### COLLAPSE MORPHOLOGIES

There are many examples of double ridge collapse in Galileo imagery. These are generally consistent with, indeed corroborative of my proposed “flowering” spiral forms.

Collapses of large double ridges, for example in the middle of the band in 46 666 0100r, and illuminations of “cuttings” by troughs, for example at the bottom LHS of 46 666 9939r, show that relaxed double ridges are fairly solid.

Low albedo collapses are tellingly most profound and extensive, consistent with regional melt genesis via ocean warmings produced by impactors.

That spiral ridges thus evidently soften, relax, partially melt into the crust is consistent with the fact that double ridges tend to be more subsided the smaller, presumably older they become.

High albedo examples of collapse are tellingly localised and adjacent to “crater” clusters, consistent with impact fracture geneses, dry subsidence.

Such evidences are consistent with spiral fragments being included, with folds, within my “intermediate forms”, as “braided sets of double ridges” or “complex maze/s of overlapping surface features” and so on.

#### **HOW DISCOVERY HAPPENED**

Consistent with inferred double ridge robustness (explained above) and band dilation (Tufts et al 2000), my tidal mechanism was a synthesis of seven observations/experiences:

- 1) The larger of Europa’s double ridges generally cut across smaller ones, consistent with succession, with increasing ice thickness, of larger-scale fold features (next paper).
- 2) Antarctic seawater ice tide cracks produce symmetrical ridges along either side during the Spring. These have the fragile forms of “petals” curling upwards and backwards, as high as 300mm.
- 3) These “petalled” ridges disappear as melt dilutes ocean surface water during the Summer, when they are replaced by symmetrical series of ridged abutments below the sea-ice surface.

- 4) "Petalled" ridges never occur at tide cracks in the freshwater ice surrounding glacier tongues, even when these are subject to the same weather and tidal movement, obviously because freshwater ice is much too brittle to produce them.
- 5) Wintry ice on Antarctic hypersaline lakes has the properties of icecream; more pliable and viscous than seawater ice, tougher too, when cold and hard. If these lakes had tides, tidal cracks, my guess is that some of them would produce spectacular Winter "petals".
- 6) My having produced the subsequent Impact Tectonogenesis volumes of this CD set.
- 7) My viewing 17ESLIBLIN01, 17ESSTRSLP01 and other images on the Internet (JPL 1999).

I thus virtually "remembered" my dual-mode mechanism from Antarctic experience, simply "applied" it to the up to ~300 times larger features of Europa.

I had observed the Antarctic examples in action many times, on sea-ice adjacent to the Vestfold Hills, 1974, always after many days of "fine", freezing weather.

Fine preceding days are probably important, consistent with tidal oscillations being the generative oscillations. Other oscillations, wind-driven waves and so on, probably having a negative effect.

The smaller-scale Antarctic dual-mode mechanism is accurately described by Figs 1, 2 (Points 2, 3) and accompanying explanation, excluding stages 5)-8) of Fig 2.

I had been so well prepared for 7), by experiences/observations 1)-6), especially 6), that I "recalled" my dual-mode mechanism soon after viewing 17ESLIBLIN01.

Then, within a few hours of my viewing the 17ESSTRSLP01 photos, 11 Feb 2002, I "perceived" as effects of super huge and huge impact (before reading referred-to explanations):

- The complex fold and double ridge texture;
- The telling dilations associated with band production;
- The splitting of double ridges.

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