The Evolution of Icy Tectonic on the Europa Satellite, the Fourth Largest Satellite of Jupiter

Abas Kangi
Department of Geology, Islamic Azad University, Shahroud, Iran
kangiabas@hotmail.com

Abstract: In view of morphology and tectonic situation, the surface of the Europa satellite includes special intricacies. In general, the most noticeable structure on this satellite is linear structures. These structures generally appear in the form of bands, ridge bands, double ridges, complex ridges and troughs. To identify the stress fields, which cause the formation of the linear structures, extension ridges, shear zone faults and superimposed linear structures, the condensation resulting from the ebb and flow on the surface of the Europa satellite has formed extension ridges on the icy crust surface. Considering the lack of subduction zones on the surface of the satellite, increase in the area of the crust resulted in the formation of stress zones in the vicinity of the ridges. In such stress zones conjugate fractures are formed. Therefore, it may be argued that the formation of pressure and extension structures take place simultaneously.

Key Words: Icy Tectonic, Europa Satellite, Jupiter**,**

تکامل تکتونیک یخی در سطح قمر اروپا چهارمین‌قمر بزرگ سیاره مشتری

عباس کنگی
استادیار گروه زمین شناسی دانشگاه آزاد اسلامی واحد شاهرود
kangiabas@hotmail.com

چکیده: سطح قمر اروپا از نظر مرفولوژی و شرایط تکتونیکی دارای‌پیچیدگیهای خاصی می باشد. بطور کلی برجسته ترین ساختمان موجود در سطح این قمر، ساختمانهای خطی است. این ساختمانها عموما به شکل bands, ridge bands, double ridges, complex ridges و troughs ظاهر گردیده اند. به کمک ریدجهای کششی، گسلها، زونهای برشی و ساختمانهای خطی سوپراینپوز شده، می توان میدان استرسهایی که باعث شکل گیری این ساختمانهای خطی گردیده اند را شناسایی نمود. در سطح قمر اروپا انبساط ناشی از نیروهای جزر و مّد سیّاره مشتری، سبب شکل گیری ریدجهای کششی در سطح پوسته یخی می گردد. با توجه به عدم وجود زونهای فرورانش در سطح این قمر، افزایش مساحت سطح پوسته، سبب تشکیل مناطق فشاری در مجاور ریدجها و پی آمد آن تشکیل‌شکستگی های متقاطع می‌گردد. بنابراین بنظر می رسد در سطح قمر اروپا شکل گیری ساختمانهای فشاری و کششی بصورت هم زمان صورت می‌گیرد.

واژه های‌کلیدی: تکتونیک یخی ، قمر اروپا ، سیّاره مشتری

1- Introduction

Basically, the surface of Europa satellite is made up of an icy crust (Pilcher et al., 1972) with lineaments that reflect the intricate history of this satellite (Greenberg et al., 1998; Greeley et al., 2000). Most bands are localities where new lithosphere is formed. Hypotheses of band formation include linear diapiric upwelling (Head et al., 1999; Prockter, 2000), possibly triggered by shear heating of subsurface ice along a fault zone (Gaidos & Nimmo, 2000; Pappalardo & Head, 2001). Ridges are long, narrow, topographically raised features that often occur in pairs. Hypotheses of ridge formation include linear diapirism (Head et al., 1999), cryovolcanic emplacement (Fagents et al., 2000), and extrusion of debris along cracks due to tidal squeezing (Greenberg et al., 1998). Ridged bands have morphologies that display characteristics of both ridges and bands and may form by a combination of ridge-forming and band-forming processes. Complex ridges are sets of overprinted, anastomosing ridges that have a similar general trend, but that locally vary in their orientations. Troughs are linear depressions that may represent early stages of lithospheric extension (Greeley et al., 2000). The landforms and tectonic features described above formed as a result of stresses in the Europan lithosphere. The primary mechanism by which stress is generated on Europa is nonsynchronous rotation (Ojakangas & Stevenson, 1989), though tidal stresses are also a component. A model of the stress field predicted for nonsynchronous rotation was formulated to explain the relationship between stress

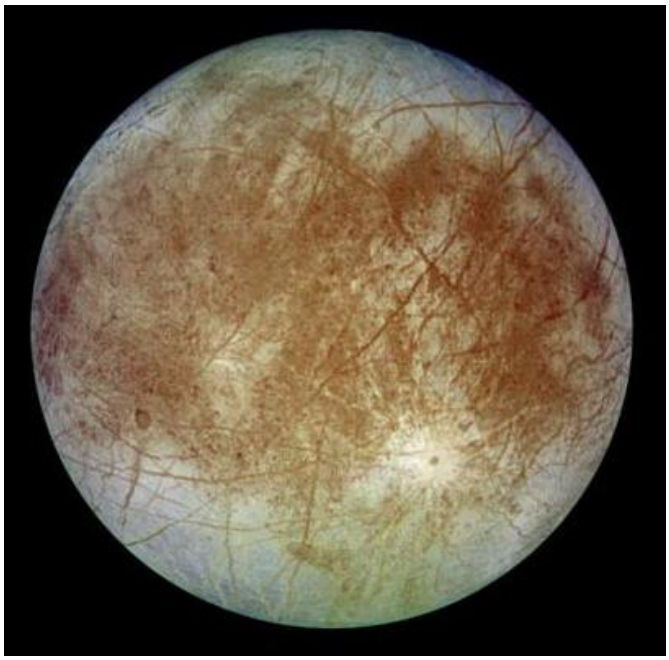


Fig.1- Europa Satellite, the Fourth Largest Satellite of Jupiter (http:// Photojournal.nasa.gov/catalog/PIA00502).

and tectonic features on Europa (Greenberg et al., 1998). Most of the lineaments are hypothesized to have formed from tensional stresses and many researchers assume that lineaments form in an orientation perpendicular to the modeled maximum tensional stress (Figueredo and Greeley, 2000; Kattenhorn, 2001). However, other investigators have suggested that at low latitudes, lineaments form as shear zones (Spaun et al., 2001). Greeley (2002), elucidated the surface structure of Europa using a novel method. Based on the en-echelon ridges and throughs present in some shear zones, They attributed the formation of pressure structures on the satellite to the low latitude zones.

In case the Europa satellite is condensed by the tidal forces, there will be a noticeable increase in the area of the satellite. On Earth, tectonic extension at mid-ocean ridges is compensated by subduction zones, where lithosphere is destroyed, however there is no terrestrial-style subduction zone on Europa. However, lack of such a mechanism on the surface of the Europa has resulted in the formation of pressure zones and adjacent to tension ridges.

Considering the lack of subduction zones, such a mechanism can form conjugate fractures in the vicinity of extension ridges and increase the thickness of the icy crust in stress zones. Thus, an increase in the area of the ridges is compensated as the icy crust thickens.

The main aim of this research is to develop a novel description about formation of linear structures on the surface of Europa. This study focuses on the simultaneous and complex formation of extension and stress structures on the surface of the satellite which are not in agreement with the existing tectonic models in Mars and Earth (Kangi, 2004 & 2005).

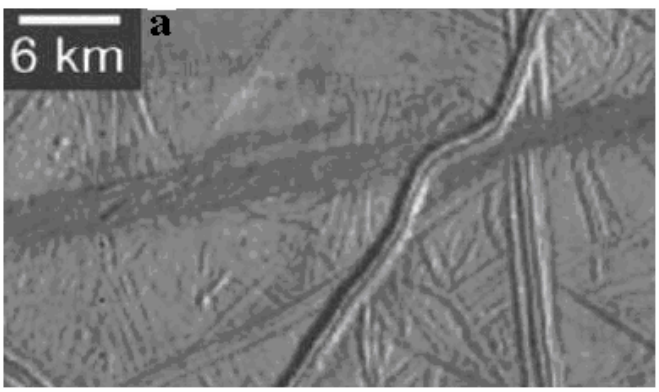
2- Main Structures

2.1- Extension Ridges

The information obtained from Galileo spaceship indicates that the temperature is 130 kelvin (-225 F) in tropical areas on the Europa. This very low temperature has formed an icy crust on the surface of the ocean water existing on the satellite. The icy cover on the surface of the satellite easily reacts to changes in temperature. Such that a decrease in the temperature as a result of outer factors (such as a shower of meteors or thermal activities can) decrease the oceans temperature and consequently reduce the thickness of the icy crust. Under such conditions, the gravity of the Jupiter and the other three satellites on the Europa icy crust will increase. Therefore, the ebb and flow, and the condensation of the icy crust will result in the domination of extension system and the formation of extension ridges on the surface of Europa satellite.

2.2- The Simultaneous Formation of Extension and Pressure Structures

The presence of extension and pressure structures superimposed on the surface of Europa satellite indicates that there is a simultaneous activity of these two force systems. Figure 1 is a picture of low latitude areas transmitted by Galileo spaceship. This picture shows that at first an extension structure of EERTS type is formed under the influence of shear system (Greely 2002). The predominance of such a system has caused the formation of en-echelon structures in the central part (Fig.2). In the next stage a ridge with a curve in the central part has cut through the shear zone. If strike-slip faulting has caused the formation of band, there would have been a pull-apart basin in the curvature area which would have resulted in an increase in the band width in that area (Fig.2b).In view of the fact that the width is the same along the band, it can be concluded that this linear structure has been formed by extension forces.



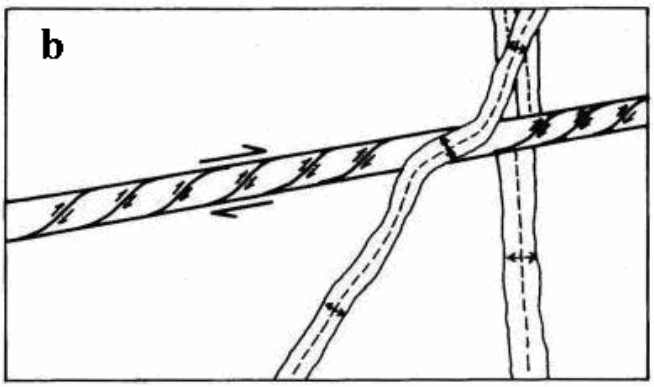
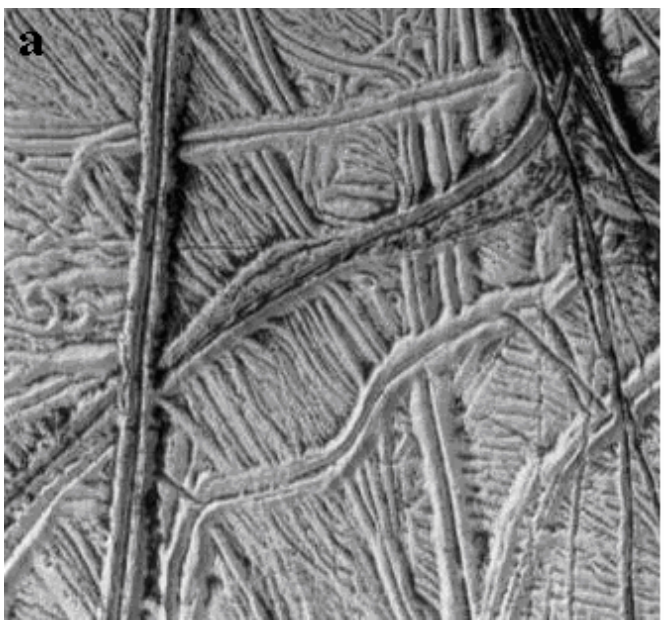


Fig. 2- (a) Mosaic of SSI imager S044991800 and S0449961865, 246 m/pixel, located at 22N, 223W, the Simultaneous Formation of Extension and Pressure Structures (adoption of Greeley 2002). (b) Map for image in "a".

Therefore, considering the presence of extension and pressure structures in the tropical areas, it seems that the formation of such structures on the surface of Europa satellite has taken place simultaneously.

2.3- Conjugate Fractures

The expansion resulting from the ebb and flow on the surface of Europa satellite causes the formation of extension ridges in the icy crust on the surface of the satellite. On account of the fact that like the Earth there are no subduction areas on the surface of the satellite, an increase in the area of the ridges can cause pressure in the adjacent areas. In these areas conjugate fractures are formed on the surface of the icy crust which is constantly the bisector of acute angle of the fractures perpendicular to the ridge axis (Fig.3). Moreover, the increase of the ridge area is compensated by the thickening of the icy crust in conjugate fractures. If



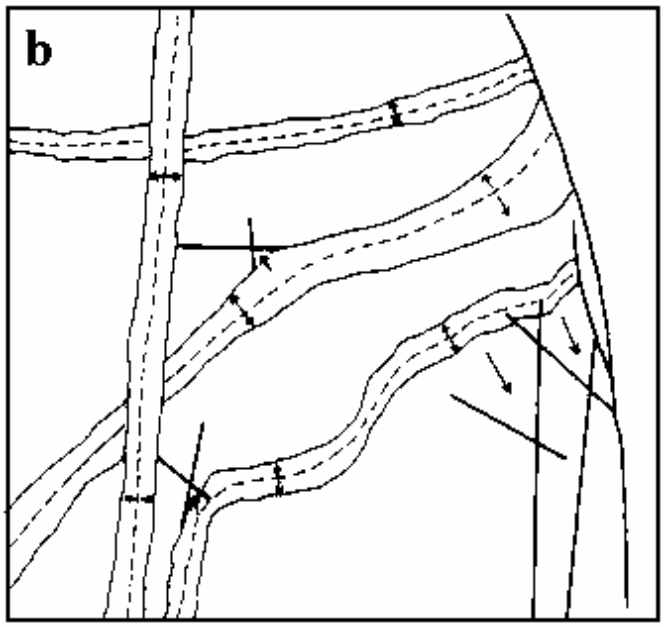


Fig. 3- (a) Image PLA01178, centered at 14 degrees south latitude and 194 degrees west longitude, covers an area of 20 km^2 on each side (Produced by JPL). Conjugate Fractures. (b) Map for image in "a".

there is excessive spreading of extension ridges, one of the conjugate fractures may change into a strike slip fault and consequently shear structures of en-echelon type are formed where these faults lie. In addition, because of the drawbacks of the icy crust, the extension fractures may be the appropriate site for the establishment of other new extension ridges during the next periods. Therefore the presence of parallel and conjugate lineaments on the surface of the satellite can be justified by the foregoing mechanism.

2.4- The Morphology of En-echelon Structures

Where the shear mechanism is functioning, en-echelon structures of EERTS type have been developed. The en-echelon structures are as complex as their morphology. In general, there is alternation of both through as well as ridge projection in these shear zones (Fig.4). Such. Morphology cannot be formed the formation of shear zones. The formation of troughs zones is only possible provided that the decrease of volume due to the melting of local ice in the direction of en-echelon structures results in the subsidence of upper parts and finally in the formation of linear depressions. Therefore, the present en-echelon structures in the shear zones can be attributed to strike slip duplex. In such conditions, then the displacement resulting from the ramifications of strike slip faults leads to an increase in heat in the direction of en-echelon lineations. Finally, this process results in the melting of ice in the direction of divergence faults and also subsidence of linear zones of en-echelon type.

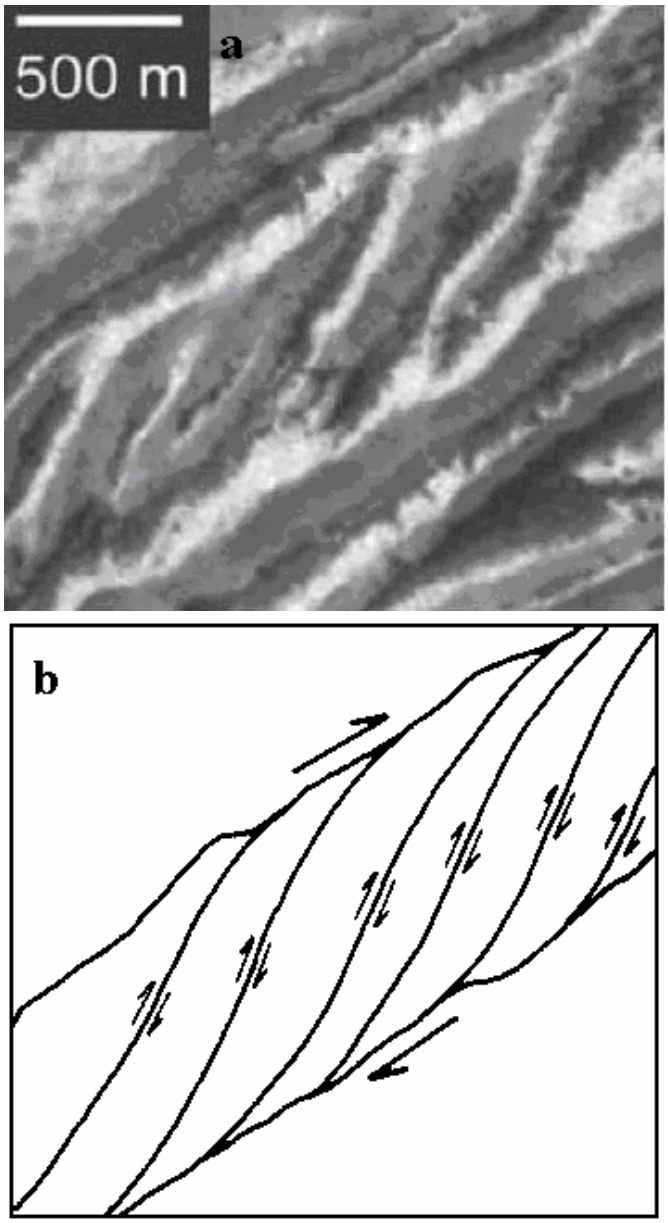


Fig. 4- (a) SSI image S042627618, 15 m/pixel, located at 17S, 217W. The morphology of en-echelon structures (adoption of Greeley 2002). (b) Map for image in "a".

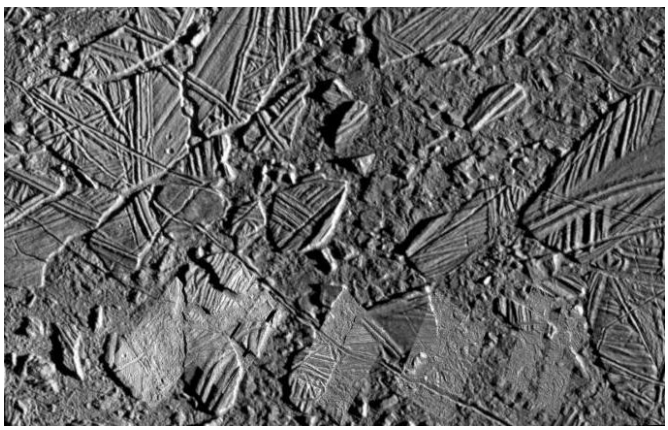


Fig. 5- Image PIA01403, the picture, centered at 9 degrees north latitude and 274 degrees west longitude, covers an area 35 by 50 kilometers (produced by Arizona State University), ephemeral local oceans.

2.5- Ephemeral Local Oceans

The conamare is shown in the right-hand side and top of figure 5. In this area sections of deformed ice masses have lain in a background of undeformed ice lands. These structures are very similar to the iceberg cubes in the Arctic oceans. It seems that these areas were formed by thermal phenomena such as the hitting of meteorites or satellites inner activities. Because of thermal activities the local ice crusts melted and the ice cubes were floated on the ocean for a short period of time. However, the low temperature of the surface of the Europa results in quick freezing of created ocean. During this period of time, the increase of the average temperature below the surface of the ocean resulted in the decrease of icy crust thickness and greater impact of the ebb and flow on the formation of extension structures.

2.6- The Mechanism of the Formation of cricoid Ridges

The distribution of tectonic structures on the surface of the Europa satellite is not the same. For this reason, in some areas certain structures are locally formed. However, in other areas on the surface of the satellite such structures are not observed. For example, cricoid ridges are among the most noticeable structures in the tropics between longitudes 190 and 230 degrees. This structure was unusually formed in this area and is not observed in other areas on the satellite. In addition to cricoid ridges, right-lateral shear zones, and pull-apart areas there are wedge ridges and normal faults (Fig. 6). Among the distinctive features of this area is the formation of a group of right-lateral shear zones all of pull-apart areas in the vicinity of each other so that they help to identify the right-lateral function of the whole shear zones. The present situation of the identified shear zones in this area is consonant with the research carried out by Hoppa (1998) according to whom all the faults in the southern hemisphere of Europa are right-lateral. Also, observed high-resolution imagery indicates that cricoid ridges are formed between two pull-apart areas adjacent to each other. Thus the activity of two parallel shear zones adjacent to the bend sets up a stress field and the resulting radial extension forms cricoid's ridges (Fig.6).

3- Conclusion

The stress field forming the lineations can be determined with the aid of certain lineations on the surface of the Europa satellite. The existence of pressure and extension structures in tropical areas implies that there has been simultaneous formation of these structures on the surface of the icy crust. Based on this theory, due to the effect of the function of the ebb and flow forces, the resultant extension ridges on the

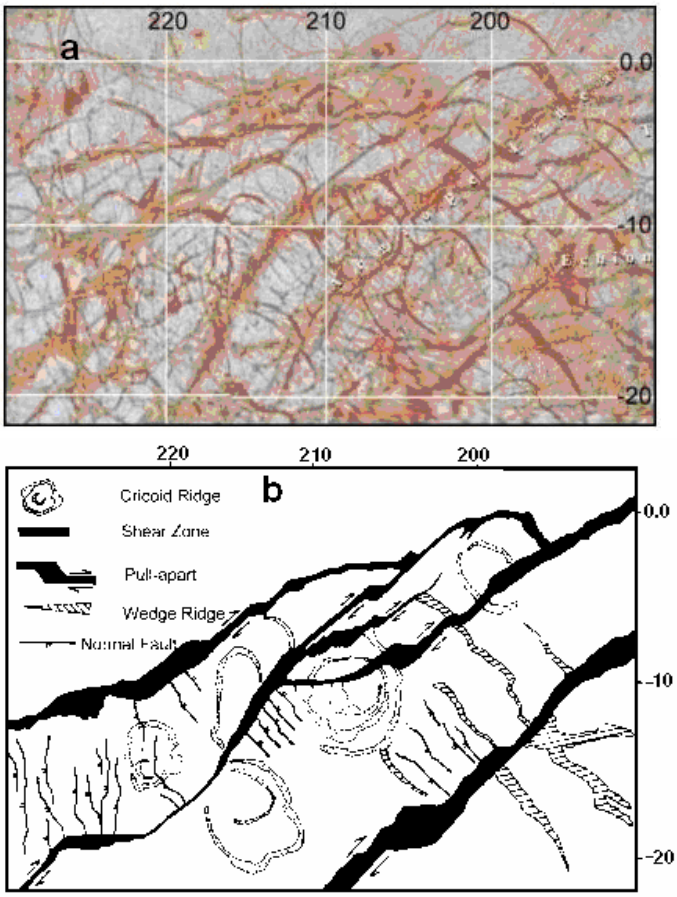


Fig. 6- (a) Image Europa, between longitudes 190 and 230 degrees, adoption of www. Planetscapes.com
(b) Map for image in "a".

surface of the Europa satellite increase the area of the crust. Considering the lack of subduction zones, the increase of the area of crust causes the formation of pressure zones in the vicinity of extension ridges. In these zones, the increase of the area of crust is compensated by the formation of conjugate fractures and the thickening of the icy crust. The morphology of en-echelon structures in shear zones is very complex. It seems that the trough depressions were formed as strike slip duplex because of the friction resulting from the displacement of en-echelon faults. Such as, icy masses were locally melted by influence of friction and due to the decrease of the volume of upper strata they subsided which caused the formation of en-echelon trough depressions. Moreover, in certain zones on the surface of the satellite where cubes of deformed icy masses lie in a background of undeformed icy lands (conamare zone), probably the ephemeral local oceans were formed during certain periods of time when the satellite was evolving. These oceans have been formed as a result of thermal activities on the surface of the icy crust.

4- References

Fagents, S. A., Greeley, R., Sullivan, R. J. & Pappalardo, R. T., 2000, "Prockter, and the Galileo SSI Teeam, Cryomagmatic mechanisms for the formation of Rhadamanthys Linea, triple band margins, and other low-albedo features on Europa", *Icarus, 144, pp. 54-88.*

Figueredo, P. H. & Greeley, R., 2000, "Geologic mapping of the northern leading hemisphere of Europa from Galileo solid-state imaging data", *J. Geophys. Res, 105(E9), pp. 22,629-22,646.*

Gaidos, E. J., & Nimmo, F., 2000, "Tectonics and water on Europa", *Nature, pp. 405, 637.*

Greeley, R., Figueredo, P. H., Williams, D. A., Chuang, F. C., Klemaszewski, J. E., Kadel, S. D., Prockter, L. M., Pappalardo, R. T., Head, J. W., Collins, G. C., Spaun, N. A., Sullivan, R. J., Moore, J. M., Senske, D. A., Tufts, B. R., Johnson, T. V., Belton, M. J. S. & Tanaka, K. L., 2000, "Geologic mapping of Europa", *Jour. Geophys. Res., 105(E9), pp. 22,559-22,578.*

Greeley, R. P. & Michalski, J. R., 2002, "En- echelon ridge and trough structures on Europa, Geophys". *Res. Lett., 29 (10), 10.1029/2002GL014956.*

Greenberg, R., Geissler, G., Hoppa, B. R., Tufts, D., Durda, D., Pappalardo, R., Head, J. W., Greeley, R., Sullivan, R. & Carr, M. H., 1998, "Tectonic Processes on Europa: Tidal stresses, mechanical response, and visible features", *Icarus, 135, pp. 64-78.*

Head, J. W., , Pappalardo, R. T. & Sullivan, R., 1999, "Europa: Morphological characteristics of ridges and triple bands from Galileo data (E4 and E6) and assessment of a linear diapirism model", *J. Geophys. Res, 104(E10), pp. 24,223-24,236.*

Hoppa, G. V., 1998, "Europa, effects of rotation and tides on tectonic processes", *Doctoral thesis, University of Arizona, Tucson.*

Kangi, A., 2004, "New Method of Terraforming**",** *JBIS, Vol. 57, NO. 1/2, pp. 67-70.*

Kangi, A., 2004, "Gusev Crater, A Mythical Crater-Lake on the Martian Surface", *JBIS, VOL. 57, NO. 9/10, pp. 313-317.*

Kangi, A., 2005, "The Mechanism of Valles Marineris Formation", *JBIS, VOL. 58, NO. 1/2, pp. 34-39.*

Kattenhorn, S. A., 2001, "Detailed fracture history of the Bright Plains region, Europa: Implications from nonsynchronous rotation models", *LPSC XXXII, abstract 1238.*

Ojakangas, G. W & Stevenson, D. J., 1989," Polar wander of an ice shell on Europa", *Icarus, 81, pp. 242-270.*

Pappalardo, R. T. & Head, J.W., 2001, "A thick-shell model of Europa geology: Implications for crustal processes", *LPSC XXXII, abstract 1866.*

Pilcher, C. B., Ridgway, S. T. & McCord, T. B., 1972, "Galilean Satellites: Identification of water frost", *Science, 178, pp. 1087-1089.*

Prockter, L. M. & Pappalardo, R. T., 2000, "Folds on Eropa: Implications for crustal cycling and accommodation of extension", *Science, 289, pp. 941-943.*

Spaun, N. A., Pappalardo, R. T., Head, J. W. & Sherman, N. D., 2001, "Characteristics of the training equatorial quadrant of Europa from Galileo imaging data: Evidence for shear failure in forming lineae," *LPSC XXXII, abstract 1228.*