CRUSTAL SPREADING ON EUROPA: INFERRING TECTONIC HISTORY FROM TRIPLE JUNCTION ANALYSIS

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Introduction: Europa, one of the Galilean moons of Jupiter, is 1565 km in diameter with a rocky core and an outer layer of H_2O approximately 170 km thick [1]. Galileo magnetometer data suggest that a large portion of the H_2O layer consists of liquid water [2], and that it is capped by an ice layer between ~1 and 20 km thick [3]. This outer shell is constantly under time-varying stress fields as a result of diurnal tides induced by the moon's proximity to Jupiter [4], nonsynchronous rotation of the decoupled outer shell [5], and possibly polar wander [6]. The effect of these fields is to crack and warp the ice shell and subsequently break it into plates.

Images obtained by the Voyager and Galileo spacecrafts have shown that Europa displays evidence for some morphologies associated with terrestrial plate tectonics [3,4,7,8]. These include (but may not be limited to) spreading centers and transform faults. Here we expand on a preliminary analysis [8] of a set of triple junctions in the south polar region of Europa whose boundaries appear to be characterized by ridges that have been pulled apart and explore its implications for determining relative spreading velocities, stability, and tectonic history.

Triple Junctions: Triple junctions are the intersection of three tectonic plates. On Earth, the boundaries of the plates that intersect can exhibit any of three types of boundary interaction: divergent (**R**idge), convergent (**T**rench), or transform (**F**ault). Considering all possible combinations of these boundaries as well as differences in the sense of subduction along a trench and shear motion along a transform boundary, the total number of unique boundary combinations is sixteen [9]. Of these, two can be considered always unstable (FFF and RRF), one always stable (RRR), and the rest stable under certain geometric conditions.

If we assume that plates act rigidly on Europa (as they typically do on Earth) and that all plate motions are circular then the relative motions between the plates that form a triple junction would not be independent [9]. This implies that at any instant in time the addition of the magnitude of the velocity vectors between each boundary in the junction must equal zero and the velocity vectors would form a closed loop (typically a triangle) [9]. Velocity diagrams that satisfy the above assumptions can be used to constrain the relative velocities and motion of all boundaries in a triple junction as well as test the stability of the junction over time.

A triple junction is kinematically stable if the orientation of each plate boundary remains constant relative to other boundaries in the triple junction over a finite time-interval [10]. This would require that the vectors of relative plate motion at the triple junction are either unchanged over time or vary proportionally [9,10]. This assumption has been shown to break down over long timescales for terrestrial triple junctions but the divergence of the shape of relative plate motion from a circle may be acceptably small on shorter timescales (~10^7 yrs) [10,11]. This is important since modeling of triple junctions that involve noncircular relative plate motion is laborious and requires knowledge about past velocities and positions of plate boundaries [10] (this would be difficult to obtain for Europa).

The age of Europa's surface (~10^7 yrs) [3] suggests that tectonic boundaries are relatively young geologically. Further, it has been suggested that the orientation of ridges and faults may be controlled by time-varying stress fields induced by nonsynchronous rotation and/or polar wander [4,5,6,12]. This would place an upper limit on the timescale of formation for these features of ~10^4 to 10^5 yrs. Using the previous assumption that over relatively short timescales circular motion is the norm, we may be able to apply the general (circular motion) method and use velocity diagrams of triple junctions on the surface of Europa to constrain the relative motion and spreading rate of ridges.

Study Area: As previously discussed, Ridge-ridge-ridge junctions are stable in all orientations for the general method. A review of ~70% of available Galileo images of Europa indicates they are the most commonly recognizable junction type on the surface. In general, ridges spread symmetrically and orthogonal to their strike [9] and this implies RRR junctions are ideal for analysis. Here we will concentrate on a set of RRR triple junctions (Fig. 1) in the south polar region of Europa (-78° lat, 121° lon).

This region can be broken into four plates by the set of junctions labeled plates A, B, C, and D in Figure 1. Each ridge shares a similar morphology consistent with mid-ocean ridge-style spreading as discussed by Prockter et al. (2002) [7]. In general, it consists of a V-shaped axial trough, a zone of hummocks oriented perpendicular to the central axis, and a set of bounding ridges. An anomalous characteristic is that the central troughs of the ridges do not meet at a point but form a triangular region at the center of the junction.

The eastern junction consists of ridges 1, 2, and 3 (Fig. 1b). Ridge 1 is ~3 km in width and strikes due north. The axial trough of this ridge strikes N5°E, contrary to our expectation of symmetric spreading. Ridge 2 is also ~3 km across with the eastern bounding ridge striking S13°E and the axial trough and western bounding ridge striking S8°E. Ridge 3 is ~4.5 km in width with its northern bounding ridge and axial trough striking N74°W while the southern bounding ridge strikes N69°W.

The western junction incorporates ridges 3, 4, and 5. Ridge 3 is crosscut by a fault between the eastern and western junctions and for the western junction it measures ~3.5 km in width with the northern bounding ridge and axial trough striking N82°W and the southern bounding ridge striking N78°W. Ridge 4 is ~4.5 km across and strikes N21°E while ridge 5 is ~6.5 km in width and strikes S35°W. Ridge 4 also shows indications of pseudo-faults near the triple junction boundary and their orientation indicates the ridge receded during formation of the junction (Fig. 1a-c).

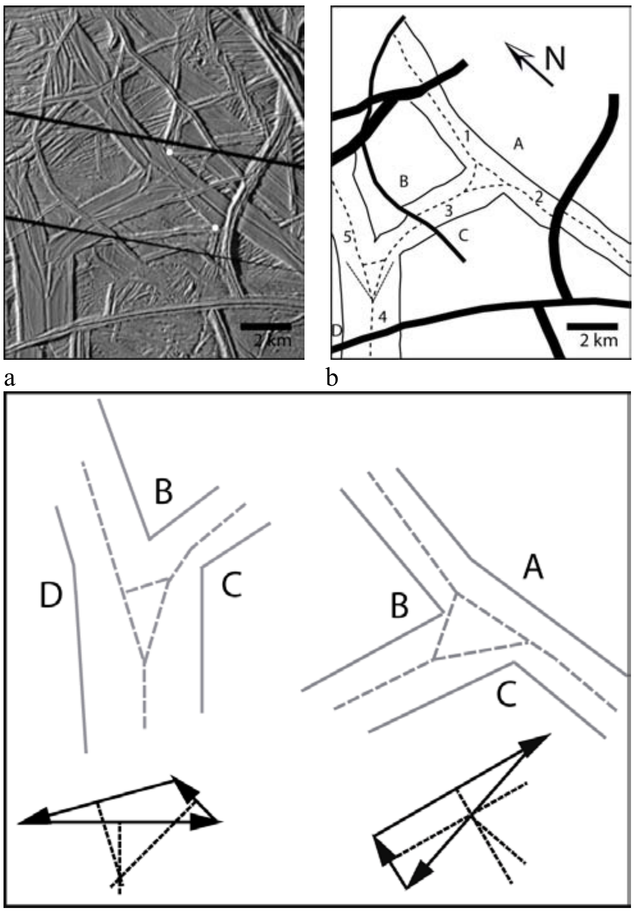

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Figure 1. a) Galileo image s0466670700_13, -78° lat, 121° lon; white dots indicate feature that can be reconstructed if left-lateral strike-slip motion is inferred; b) sketch map indicating ridges with central grooves (dashed lines) and triangular groove sets at center of each junction; plates are labeled A-D and ridges 1-5; c) sketch map showing relative velocity diagrams and points of instantaneous stability for each junction.

Results: The relative velocity diagram for the eastern junction (Fig. 1c) appears to contradict the general assumption that when ridges form contemporaneously, width is proportional to velocity [9,10,11]. There appear to be no indications that these ridges did not form contemporaneously; therefore another explanation is necessary. An answer may be found in the orientation of the ridges.

The near parallel orientation of ridges 1 and 2 coupled with the perpendicular orientation of ridge 3 with respect to the other two ridges is more indicative of a FFR orientation than a RRR. With this in mind we attempted to reconstruct the boundary between plate A and plates B and C with transform motion and discovered that a favorable reconstruction could be achieved with left lateral motion of ~16.5 km. This may imply either a change in tectonic style from FFR to RRR late in the history of the boundary or possibly a significant amount of oblique spreading occurred during its formation.

The western junction indicates an instantaneously stable RRR junction in which ridge 4 has receded over time. Evidence for this can be found in the presence of pseudo-faults extending from the trough intersection within ridge 4 as well as the relative velocity diagram itself. A relative velocity diagram in which the perpendicular bisectors of the relative velocity vectors cross outside of the relative velocity triangle (Fig. 1c) indicates that one of the boundaries is receding [11].

The triangular regions found at each junction may represent migration of the junction over time (western junction) and/or a change in boundary type (eastern junction). The idea that a junction may repeatedly jump from one mode to another and still be compatible with the same relative velocity triangle, was first put forward by Sclater et al. (1976) [13] and may provide an explanation for the possible transform motion inferred along ridges 1 and 2.

Conclusions: Given the existence of numerous features on the surface of Europa that share morphological characteristics with terrestrial tectonic features [4,7,8], it is reasonable to assume that many of the techniques used to understand the tectonic history of Earth could be applied to Europa. Here we apply terrestrial techniques of triple junction analysis to make inferences about the tectonic history of a set of triple junctions in the south polar region of Europa

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