
**Introduction:** Large blocks of Europa’s surface are observed to have moved laterally by tens of kilometers in Voyager images [1,2] and Galileo images [3,4,5]. Examination within a spherical plate-motion context found that Europa’s surface may be acting as a set of laterally moving rigid plates [6]. Careful sequential reconstruction of motions along several boundaries found that Europa exhibits all three types of plate boundaries observed on Earth - divergent, transform, and convergent - which are required for a plate tectonic paradigm of lateral surface motions [7].

By combining the spherical plate motion context [6] with sequential reconstruction along boundaries [7] and expanding it out to a larger study area, we are now in a position to make inferences about observed plate-like behavior on Europa. A major point is that plate motions on Europa may be regionally constrained and episodic, rather than the continuous, global system we observe on Earth.

**Study areas:** We have examined five areas on the antijovian hemisphere, centered around 145°E longitude, using a continuous mosaic of Galileo images sampled to 165 m/pixel (Figure 1). Previous works contain more detailed descriptions of lateral motions in portions of these areas: Falga [7,8], Belus [5], Castalia [6,9], Libya [4,10]. was prepared covering all of these study areas.

**Method:** In each study area, we begin the reconstruction process by searching for lateral offsets of preexisting surface features. Following groups of offset features, we develop a map of potential plate boundaries. The offset features then become piercing point indicators that allow us to later examine the kinematics along each plate boundary. The next step is to derive the time sequence in which the various plate boundaries were active [e.g., 7], using cross-cutting relationships to determine sequences of motion, or identifying triple junctions that show simultaneous motion. We then use GPlates software [11] to manually define a set of staged Euler pole rotations that satisfy the sequence and kinematics of the plate boundaries. In two of the study areas, Libya and Castalia, we compared our manual approach to inverse modeling of the total reconstruction poles based on aligning piercing points [6,10]. The two methods agree on the general motion of the plates. The manual staged GPlates method prevents nonphysical motion paths where plates would pass through each other, while the inverse modeling approach can quantify the errors associated with a given two-plate reconstruction.

**Observations:** Figure 2 provides a high-level summary of the detailed observations of plate boundary motions in the reconstructed areas. In the following high-level summary, lateral motions < 10 km are labeled “minor” and > 10 km are labeled “major,” while left-lateral and right-lateral strike-slip motions are labeled LL and RL, respectively. The Falga area shows minor E-W divergence late in time, major LL motion throughout time, and major N-S convergence early in time. The Minos area shows a few discontinuous boundaries with minor LL offsets but does not appear to be organized into a system of plates. The Belus area shows very little divergence, minor LL motion throughout time, and minor N-S convergence early in time. The Castalia area shows major N-S divergence, progressing through time from the northern part of the area to the southern part, mixed minor RL and LL motion through time, and minor E-W convergence late in time. The Libya area shows major N-S divergence and major RL motion throughout the time sequence.

In none of the regions do we observe offsets along plate boundaries > 100 km, though the constrained area of Galileo imaging may bias this result. There does appear to be an upper limit on the width of bands on Europa [12], consistent with our result. We also never observe material formed in divergent bands being consumed in simultaneously operating subsumption zones, so there is no analogy on Europa for the continuous conveyor belt of oceanic plate material on Earth.

It is important to note what we can infer about the timing of plate motions. None of these areas exhibit plate boundaries that are at the top of the sequence of cross-cutting geological features; many are overprinted by younger chaos and ridges. The plate boundaries in Falga and Belus appear to be crosscut by the same ridges that extend across Minos, making these motions indistinguishable in the time sequence. Ridges continuing from Belus to Castalia imply that all of the activity in Belus predates the activity in Castalia. We cannot compare the relative ages of the Castalia and Libya plate motions due to a large region of chaos and the presence of Agenor Linea in between these areas.

**Implications:** The prevalence of LL motions along plate boundaries in the northern hemisphere and RL in the southern hemisphere implies that tidal forces may play a significant role in determining the direction...
of plate motions [cf. 5]. One possibility is that some plate motions are dominated by edge-driven tidal effects [13]. The observation that none of the plate boundaries are at the top of the stratigraphic sequence indicates that plate-like tectonic behavior on Europa does not appear to be happening today, at least not in the observed regions. The difference in timing of plate motions, especially between Castalia and Belus, indicates that one region of Europa could experience plate-like behavior at the same time that a neighboring region does not. Thus, plate tectonics on Europa appears to be regional and episodic.

The observation that Europa plate tectonics lacks the oceanic plate “conveyor belt” and that none of the offsets are more than 100 km implies that there may be some self-limiting factor to the mechanism driving plate motions on Europa. Perhaps the process “choke up” after a certain amount of material is consumed, and the motions grind to a halt. This behavior is consistent with our numerical results mapping out convective regimes in ice [14], indicating that while mobile-lid behavior is possible on Europa, it is limited by both the strength of the ice and the convective vigor of the system. Though studying the mechanism for ice subduction [15] is still important for understanding the initial stages of plate motion, it is less important that the solution be self-sustaining in order to explain the observations.


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Figure 1. Locations of study areas for plate reconstructions. This image covers an area from 70°N to 70°S and 115°E to 175°E.

Figure 2. Graphical summary of dominant motions between plates in each study area. See “observations.”