MODELING PLATE MOTION ON EUROPA: PHAIDRA LINEA G. Wesley Patterson[1] and Carolyn M. Ernst[1], [1]Planetary Exploration Group, Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723, Wes.Patterson@jhuapl.edu.

Introduction: The surface of Europa has been pervasively modified by a variety of linear to curvilinear tectonic features that are both recent and globally distributed. It has been shown that these features can serve as the boundaries of lithospheric plates that have rotated and/or translated with respect to each other [1,2]. Attempts to reconstruct many such boundaries have generally assumed that the satellite's elastic lithosphere behaves rigidly [3-5]. However, research done examining the accuracy of those assumptions has suggested that non-rigid behavior can accommodate a significant fraction of deformation [6,7]. To evaluate the significance of this behavior, we use plate motion modeling to determine the presence and magnitude of non-rigid behavior associated with a multi-plate system found on the satellite's equartorial trailing hemisphere (Fig. 1).

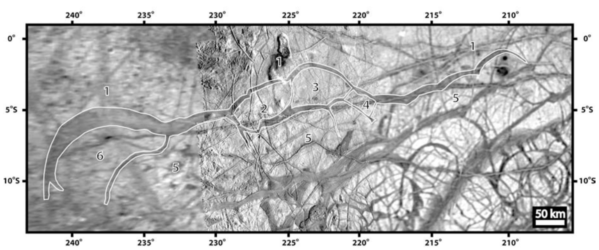

Fig. 1. Context image of Phaidra Linea (outlined in white) taken from the USGS controlled photomosaic of Europa (I-2757). Plates produced by the formation of Phaidra are numbered 1-6.

Methodology: In terrestrial plate motion analyses, three methods have been utilized to quantitatively test the assumption of plate rigidity [8]. All involve determining the closure of a plate circuit consisting of three plates that meet at a triple junction (*i.e.*, the intersection of three plate boundaries). Two of the methods require information that is not currently available for Europa (*i.e.*, geodetic or instantaneous plate velocity data). The third method uses plate reconstruction data [9,10], requiring a description in terms finite rotations.

The motion of a plate on a spherical surface can be described, mathematically, by a finite rotation, R[E,Ω], of the plate by Ω degrees about a location, E, passing through the center of the sphere (*i.e.*, an Euler pole). In matrix notation, R is defined by the cosines of the angles Ω between each of three rotated axes (components of E in Cartesian space). For a plate circuit, closure is acheived when the finite rotations for each two-plate boundary in the circuit sum to zero.

Using a modifed version of a modeling technique developed specifically to calculate finite rotations for two-plate sytems on Europa [7], we have begun to assess the rigidity of a collection of lithospheric plates defined by a prominent band that has been informally referred to as Phaidra Linea (Fig. 1).

Analysis: Phaidra Linea is located along Europa's trailing equatorial hemisphere, stretching from 11°S, 241W° to 2°S, 208W°. Several bifurcated segments of the band are clearly observed and cross-cutting relationships indicate they formed contemporaneously. This suggests that the formation of Phaidra divided the surrounding region into 6 plates (Fig. 1). It also suggests the presence of 10 triple junctions.

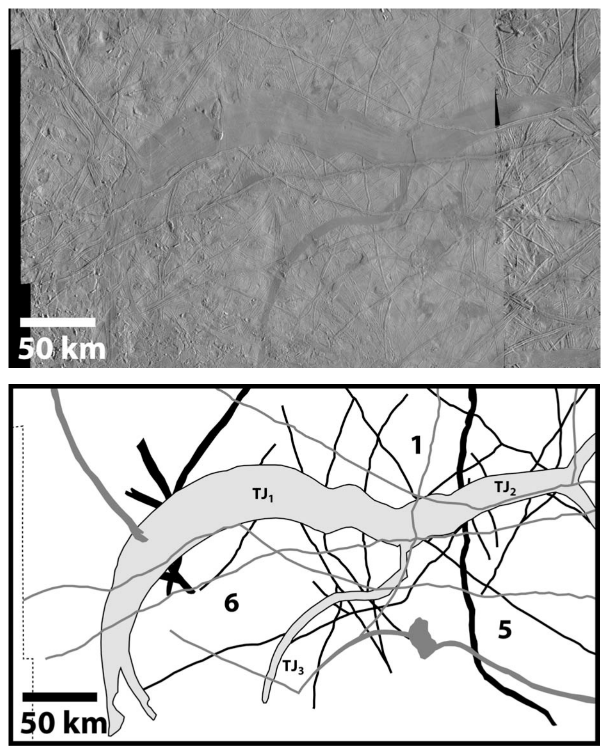

Fig. 2. (top) Phaidra Linea runs east-west through the center of this image acquired during the E11 encounter of the Galileo mission at a resolution of 220 m/pixel. (bottom) Sketch map indicating Phaidra with a black outline and gray fill. Plates defined by this feature are numbered 1,5, and 6 and prominent features that post-date the formation of the band complex are shown in gray. Preexisting features offset by the formation of Phaidra Linea are shown in black. For descriptive purposes, we refer to the portions of Phaidra that define the junction as TJ_{1-3}.

We have previously analyzed one of the triple junctions associated with Phaidra Linea [11]. It is located at 7°S, 233°W and represents the intersection of the plates 1, 5, and 6 (Fig 2). Here portions of Phaidra comprise 3 plate boundaries in this system (TJ_{1-3} – Fig. 2). That work suggested that deformation associated with the interactions of these plates was accommodated primarily through rigid behavior (Table 1). However, additional error analysis is required to uniquely determine the behavior of that system.

Table 1.

Finite Rotation	Location (°) Lat.	Location (°) Lon.	Rotation (°)	σ_i^2 (km^2)	σ_f^2 (km^2)
$^{1}TJ_{1}^{6}$	-7	225	6.7	1710	2.46
$^{1}TJ_{2}^{5}$	-5	223	5.8	530	2.05
$^{6}TJ_{3}^{5}$	-23	257	-0.60	49.8	0.101
$^{5}TJ_{3}^{6}$	-23	257	0.60	49.8	0.101
$^{1}TJ_{2}^{5} + {}^{5}TJ_{3}^{6}$ [a]	-7	225	6.1		
$^{1}TJ_{1}^{6} + {}^{6}TJ_{3}^{5}$ [a]	-5	223	6.4		
$^{1}TJ_{2}^{5} + {}^{5}TJ_{3}^{6} + {}^{6}TJ_{1}^{1}$ [a]	8	33	0.42		
$^{1}TJ_{1}^{6} + {}^{6}TJ_{3}^{5} + {}^{5}TJ_{2}^{1}$ [a]	-8	213	0.42		

[a] A variance was not determined for combinations of two-plate systems.

Another portion of Phaidra Linea, located between 230°W and 219°W, contains several interconnected bifurcations of the band (Fig. 3) and we refer to this portion of the linea as the Phaidra band complex (BC). This region encompasses 5 of the 6 plates and 9 of the 10 triple junctions observed in association with the linea. Here portions of the band comprise 7 plate boundaries (BC_{1-7} – Fig. 3). BC_1 and BC_2 represent the E-W trending portions of the Phaidra band complex, BC_3 and BC_5 represent two N-S segments, and BC_4, BC_6, and BC_7 represent segments of the complex that interact with BC_1 and BC_2, producing plates 2-4.

For these junctions, we will use our modified modeling technique to determine finite rotations describing the reconstruction of each of the 7 plate boundaries defined by Phaidra Linea. We will then combine rotations associated with each triple junction in this system of plates into plate circuits (*e.g.*, plates 1-2-3, 1-3-4, 2-3-5, *etc.*) and test them for closure. To uniquely determine the behavior of each plate motion circuit, we are incorporating error analysis techniques that have been pioneered for combining finite rotations involved with terrestrial plate motion analyses [*e.g.*, 12-14].

Summary: To evaluate the significance of non-rigid behavior of Europa's lithosphere, we are using plate motion modeling to determine the presence and magnitude of non-rigid behavior present within a complex system of plates on Europa defined by the prominent band Phaidra Linea. This work will lead to a better understanding of how Europa's elastic lithosphere responds to strain, how plate motions affect the surface history of the satellite, and how its elastic lithosphere accommodates compressional strain.

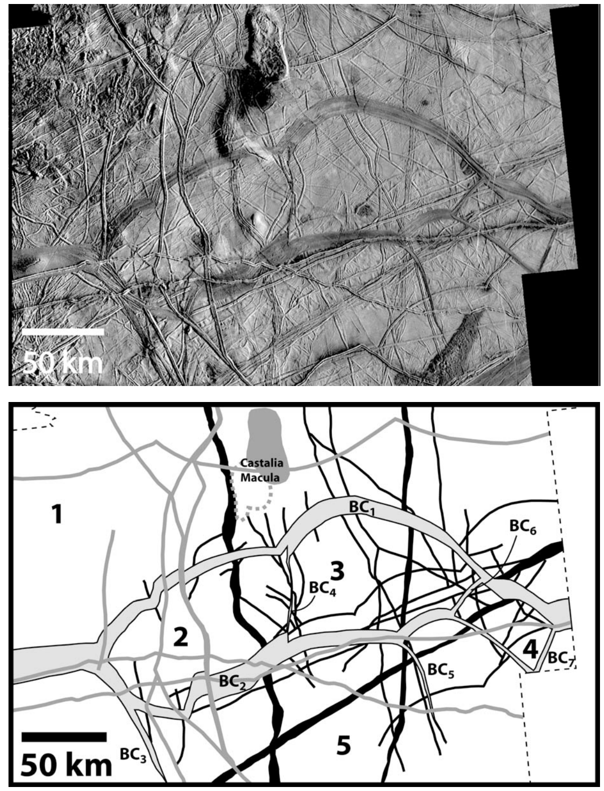

Fig. 3. (top) Phaidra Linea runs east-west through the center of this image, acquired at a resolution of 220 m/pixel during the E17 encounter of the Galileo mission. (bottom) Sketch map indicating the Phaidra band complex with a black outline and gray fill. Plates defined by this feature are numbered 1-5 and prominent features that post-date the formation of the band complex are shown in gray. Preexisting features offset by the formation of Phaidra Linea are shown in black. Portions of Phaidra that define plate boundaries are labeled BC_{1-7}.

References: [1] Schenk and McKinnon (1989), Icarus, 79, 75–100; [2] Sullivan et al. (1998), Nature 391, 371-373; [3] Tufts et al. (1999), Icarus 141, 53-64; [4] Sarid et al. (2002), Icarus 158, 24-41; [5] Patterson and Pappalardo (2002), LPSC XXXIII, #1681; [6] Pappalardo and Sullivan (1996), Icarus 123, 557-567; [7] Patterson et al. (2006), JSG 28, 2237-2258; [8] Gordon (1998), Ann. Rev. Earth Planet. Sci. 26, 615-642; [9] Royer and Chang (1991), JGR 96(B7), 11,779-11,802; [10] Royer and Gordon (1997), Science, 277, 1268-74; [11] Patterson and Prockter (2010), LPSC XXXXI, #2183; [12] Gordon et al. (1987), G. Res. Lett., 14(6), 587-590; [13] Kirkwood et al. (1997), Geophys. J. Int., 137, 408-428; [14] Chang et al. (2000), Statistical Science, 15(4), 342-356.