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Liliane Burkhard

'Reconstructing Plate Motions on Jupiter's Ganymede with GPlates'

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Reconstructing Plate Motions on Jupiter's Ganymede with GPlates

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Liliane Burkhard

Thesis Advisor

Dr. Bridget Smith-Konter

I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality.

THESIS ADVISOR

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Dr. Bridget Smith-Konter

Department of Geology and Geophysics

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ABSTRACT

Ganymede's fractured icy surface reveals many large-scale, morphologically distinct regions of inferred shear and strike-slip faulting that could be important to the structural development of its surface and the transition from dark to light (grooved) terrain. Tidal stress modeling of the Jupiter-Ganymede system suggests that surface stresses on Ganymede may be sufficient to induce shear failure and generate strike-slip offsets of large icy territories. To further investigate possible past strike-slip plate-like motions on Ganymede, we perform a plate reconstruction using a regional mosaic of high-resolution Galileo data to produce an interactive reconstruction and visualization through geological time, specifically of the grooved terrain of Dardanus Sulcus. Careful interpretation of Galileo imagery suggests consistent offset of the Dardanus Sulcus region of roughly 45 km along a NE-SW trending fault of approximately 150 km length, appearing bright against the dark terrain. We performed a detailed mapping study of this region and used the GPlates software package to model hypothesized plate motions of Dardanus Sulcus on a sphere while conserving the original Galileo images in their original geographic locations. Such a reconstruction is important for refining structural models of faulting on Ganymede, geodynamic models of Ganymede's icy shell, and astrobiological studies of Ganymede's underlying ocean, as submerging plates can transport possible nutrients into the underlying ocean. By investigating a potential evolutionary sequence of strike-slip structures, we gain an improved representation of the structural and evolutionary history of the deformation of Ganymede's large-scale strike-slip offsets. As strike-slip tectonism appears to be an integral part of the grooved terrain process, future work will focus on examining structurally more complex regions and how the deformation has affected the global surface of Ganymede.

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CHAPTER 1. INTRODUCTION

1.1 Ganymede Background

Ganymede is the third Galilean moon of Jupiter and the Solar System's largest satellite with a radius of 2631 km. Ganymede orbits Jupiter at a distance of 1,070,400 km, completing a full revolution every 171.6 hours (or roughly 7 days and 3 hours). It is in Laplace resonance with sister moons Europa and Io: for every orbit of Ganymede, Europa orbits twice and Io orbits four times (Schenk, 2010). Like most moons, Ganymede is tidally locked where one side is always facing Jupiter (Fig. 1). Ganymede's bulk composition is about 60% rock and 40% ice. Gravity data from the Galileo spacecraft indicates that Ganymede is strongly differentiated with a crust, mantle and core (Schenk, 2010). Ganymede is the only known moon to have a magnetic field, suggesting that it contains a convecting core of liquid iron alloy. Ganymede has a subsurface liquid water ocean with a thick water ice crust (Pappalardo et al., 2004). Exact depths of these layers are unknown but it is assumed that the subsurface ocean is at least 150 km deep, which is considerably deeper than Europa's (Schenk, 2010).

At average surface temperatures of 100 K (-173° C), the crustal ice is very hard and can consequently display similar behavior to terrestrial rock. Ganymede's surface consists of roughly 1/3 dark and 2/3 bright albedo terrain. Dark terrain units are considered to be the oldest preserved material on Ganymede, containing a greater fraction of rocky material than the bright ice-rich terrain. Imagery from the Galileo spacecraft reveals an extensively cratered and fractured surface with indication of strike-slip faulting. The geology of the light terrain is comparable to terrestrial rift zones and occupies long sulci (sinuous bands or deformation zones) between units of dark terrain (Bedle and Jurdy, 2005). The light, or commonly called "grooved", terrain indicates grooves of wide swaths of parallel spaced troughs and ridges as high as 700 m and thousands of km long (Schenk, 2010).

Ganymede's icy surface reveals many large-scale, morphologically distinct regions of inferred shear and strike-slip faulting that could be important to the structural development of its surface and the transition from dark to light (grooved) terrain. However, a global analysis for the role of strike-slip tectonism is lacking as studies for Ganymede have usually focused on the mechanisms for extensional tectonism, which has been broadly recognized as the leading process that defines the present-day surface (Pizzi et al., 2017). Both preliminary and ongoing research by collaborators suggests strong evidence for strike-slip displacement, in addition to extensional deformation, along several of Ganymede's sulci (Collins et al., 1998; Pappalardo et al., 1998; Patel et al., 1999; Prockter et al., 2000; Head et al., 2002; Pappalardo and DeRemer, 2003; Pappalardo et al., 2004; Pappalardo and Collins, 2005, Cameron et al., 2017). Thus a comprehensive analysis of multiple styles of tectonic deformation of Ganymede is critical toward understanding the geologic evolution of icy moons.

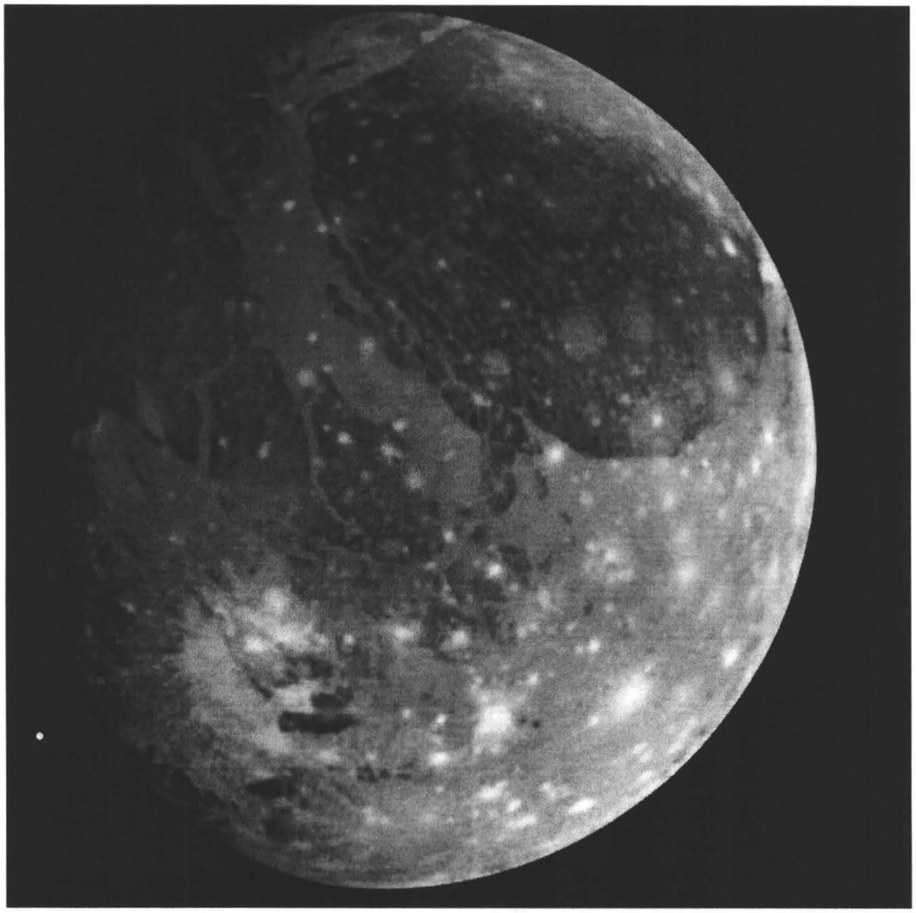


Figure 1
Natural color view of Ganymede's anti-jovian hemisphere (side facing away from Jupiter) from the Galileo spacecraft during its first encounter with the moon. The sun illuminates the surface from the right and north is to the top of the picture. The brownish-gray color is due to mixtures of rocky materials and ice. Bright spots are geologically recent impact craters and their ejecta. The images that combine this color image were taken on June 26, 1996 (image credit: NASA/JPL).

Recent tidal stress modeling of the Jupiter-Ganymede system suggests that surface stresses on Ganymede may be sufficient to induce shear failure and generate strike-slip offsets of large icy territories (Cameron et al., 2016; 2017). In conjunction with this work, we performed a detailed mapping analysis of strike slip indicators, focusing on eight regions of high-resolution Galileo spacecraft imagery (Smith-Konter et al., 2014; Burkhard et al., 2015; Seifert et al., 2016; Cameron et al., 2016) (Fig. 2). We have found ubiquitous examples of strike-slip indicators at every examined site, as well as in every terrain type. The mapped regions also share similarities in stages of deformation (Cameron et al., 2017).

To further investigate strike-slip indicators, particularly those that suggest obvious lateral offset which may have accommodated past plate-like motion on Ganymede, this study focuses on an example plate reconstruction analysis of the grooved terrain of Dardanus Sulcus. Using a regional mosaic of high-resolution Galileo data, we develop an interactive reconstruction and visualization of the apparent 45 km right-lateral offset of Dardanus Sucus The results of this project, in particular, will further illuminate the sequential history of grooved terrain formations like Dardanus on Ganymede, an potentially have applications for other banded deformation zones throughout the solar system.

1.2 Data

Telescopic spectra have been used to investigate Ganymede's surface since the late 1950's and are still of great value for present studies. Earth-based observations continue to help advance our understanding of atmospheric emissions as well as the distribution of oxygen. The first flyby imaging of Ganymede was realized in December 1973, when the Pioneer 10 spacecraft revealed darker and brighter surface swaths with its simple spin-scan Imaging Photopolarimeter (Gehrels, 1976). The greater diversity of Ganymede's surface was not recognized until Voyager 1 and 2 began photographing Ganymede in March and July of 1979. The Voyager spacecrafts were able to image almost the entire surface at a resolution of ~500-1000 m/pixel. The returned images suggested that strike-slip faulting might have taken place but it was not until high resolution (<200 m/pixel) Galileo images from 1996 provided strong evidence for major strike-slip faulting zones, offsets along some faults and for a component of distributed shear in forming grooved terrain (Pappalardo et al., 2004). From this data, we can infer features of strike-slip faulting such as en echelon structures, strike-slip duplexes, offset features and strained craters from Galileo high-resolution images, which were acquired during six close encounters with Ganymede. However, the high-resolution Galileo coverage is limited to certain areas and thus we must extrapolate conclusions to other regions. To this day, the Voyager data remains central to our understanding of Ganymede.

The USGS assembled a global image of the best available data from the Voyager and Galileo missions, resampled at a resolution of 1 km/pixel (Fig. 2) (USGS Astrogeology Center, 2016). To reach this uniform resolution, 12% of the surface area imaged at slightly higher resolution had to be degraded. Galileo imaged the leading and trailing hemispheres of Ganymede, whereas the sub-jovian region, the area locked to face Jupiter, was covered by Voyager 1 and the anti-jovian region, the area facing away from Jupiter, by Voyager 2. The image data contained in this mosaic differ widely in respect to their viewing angles and lighting. These differences can result in incomplete analysis of terrain features and can obstruct the characterization of geologic units.

By using these Voyager and Galileo images, we have mapped examples of tectonic structures on Ganymede and documented the morphology and the relationship among them (Cameron et al., 2017), which we can now use to visually reconstruct the movements of the surface. For this study, we will focus on Dardanus

Sulcus (13°W, 18°S), which has not been analyzed in detail to test that it is a true lateral offset. In this study we perform a reconstruction of the inferred offset area using GPlates to test the hypothesis of large-scale strike-slip offset and evaluate the regional history.

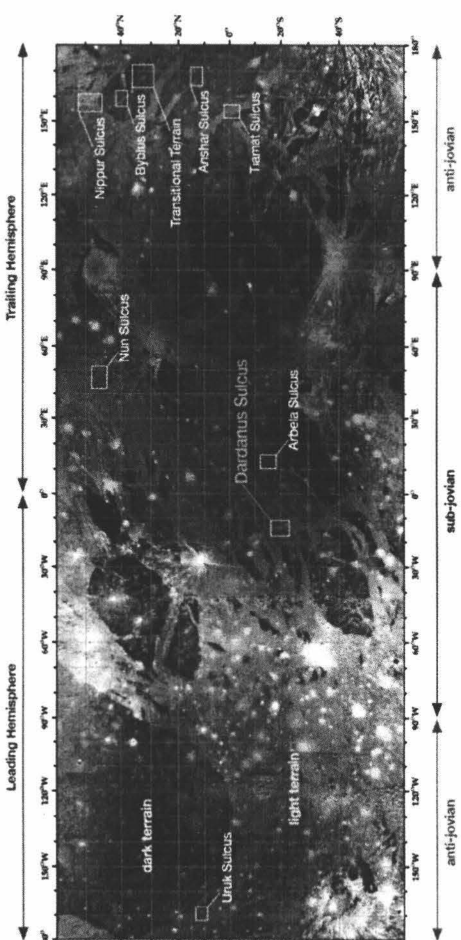


Figure 2
Global image mosaic of Ganymede in Mercator projection consisting of Galileo and Voyager imagery, resampled at a resolution of 1 km/pixel (USGS).
Examples of dark and light (grooved) terrain as well as hemispheres are labeled.
Orange box marks location of Dardanus Sulcus. Other mapped regions indicated in white.

1.3 Material Units and Faulting

Generally, we divide Ganymede's surface into two principal terrain types, which display differences in surface morphology, crater density, and albedo: dark terrain and light (grooved) terrain. Approximately 1/3 of the surface is covered in relatively old regions of heavily cratered dark terrain that is covered in low albedo regolith. Large-scale furrows crosscut much of this terrain and the darkest regions are found in topographic depressions like troughs and crater floors. Based on crater density measurements, the dark terrain is estimated to date >4 Gyr, making it the oldest preserved surface on Ganymede (Zahnle et al., 2003). However, crater densities on neighboring Callisto are higher, suggesting that Ganymede's surface is not primordial (Shoemaker and Wolfe, 1982).

Vast swaths of light grooved material that encircles the globe cover the other 2/3 of the surface. This high albedo material exhibits a significantly lower crater density than the dark material and crosscuts the older dark terrain with sub parallel ridges and troughs. Light terrain was likely emplaced between 400 Myr and 4 Gyr ago (Zahnle et al., 2003). Evidence for extension and strike-slip tectonism is far more widespread in light terrain (Cameron et al., 2017). Many studies have focused on the origin of this light grooved terrain and it is mostly believed to be tectonically-related, developed within an extension-dominated surface through the modification of dark material by tectonic and cryovolcanic resurfacing processes (Shoemaker et al., 1982; Collins et al, 1998; Pappalardo et al., 2004; Pizzi et al., 2017). However, as we infer many areas with structures demonstrating strike-slip indicators on Ganymede, a component of horizontal shear may have also shaped the light grooved terrain (Murchie and Head, 1988).

For studying fault geometry and development on Ganymede, we rely on Earth-analogues (Naylor et al., 1986; Woodcock and Fisher, 1986; Pappalardo and Greeley, 1995) and an assumed linear elastic ice rheology. Tedious mapping of high resolution Galileo imagery has allowed for the detected many diagnostic structures indicative of strike-slip faulting (i.e., Pappalardo and DeRemer, 2003; Burkhard et al., 2015), such as the offset structure at Dardanus Sulcus or en echelon faults (Fig. 3), strained craters, and strike-slip duplexes in many other regions (Fig. 4).

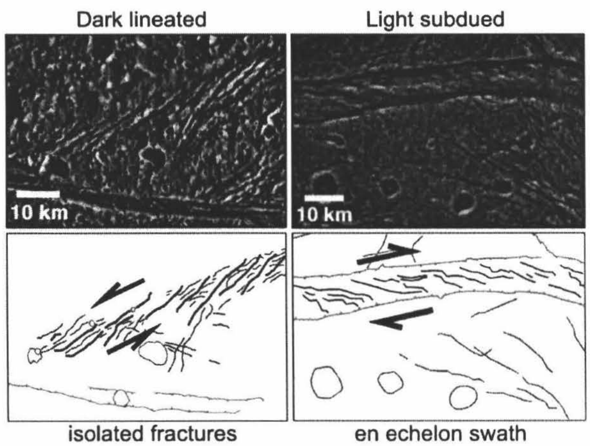


Figure 3
Examples of echelon structures on Ganymede with sketched maps and inferred shear sense. Troughs are red with scarps indicated in green. (Pappalardo and DeRemer, 2003)

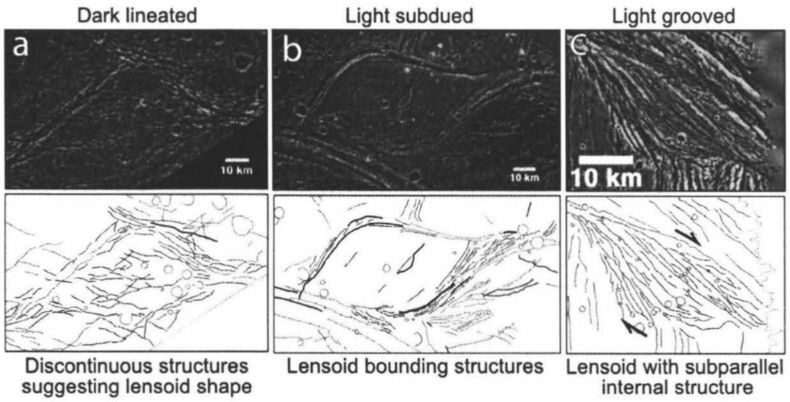


Figure 4
Examples of fault duplexes and duplex-like structures on Ganymede with sketched maps. (Pappalardo and DeRemer, 2003)

1.4 Surface Stresses

As Ganymede is fully differentiated into a solid core, a convecting outer core of liquid iron alloy, a subsurface ocean and a decoupled, viscoelastic lithospheric icy shell, the tidal stresses at the surface can be derived from the gravitational potential of Jupiter. Diurnal tides are caused by Ganymede's eccentric orbit within the gravitational field (Wahr, 1981). Non-synchronous rotation (NSR) is the relative motion of the shell to Ganymede's core (Wahr et al., 2009). Global tidal stress models due to NSR and orbital eccentricity using gravitational potential theory generate significant fault-normal and shear stress magnitudes that could promote both extensional and shear types of surface deformation on Ganymede (Cameron et al., 2016; 2017a).

It has been widely recognized that extensional tectonics is the leading process that defines the present surface of Ganymede (Pappalardo et al., 2004; Pizzi et al., 2017). To explain the origin of extension, various models have been proposed such as global expansion (Squires, 1980) and convection-driven resurfacing (Hammond and

Barr, 2014). Global expansion has been inferred as the result of differentiation or the passage through one or more Laplace resonances in combination with tidal heating (Bland et al., 2009). Simulations have shown that the occurrence of convection depends on the heating rate and therefore the eccentricity and the width of the subsurface ocean (Behounkova et al., 2013). Depending on its orbital configuration, Ganymede could switch from a conductive to a convective state.

A volume expansion of Ganymede through heating could generate extensional fractures through tensile stresses, which form conduits for the upward propagation of liquid water or ductile ice, resulting in emplacement of new bright ice-crust. This process can be compared to the Earth's oceanic spreading centers. As a possible consequence, Ganymede's widespread curvilinear pattern close to the equator can be interpreted in direct relation to the global expansion model (Pizzi et al., 2017). Other factors such as radiogenic heating have been proposed for expansion models. However, this kind expansion and the accumulation of surface stress would occur over several billion years. It is unclear if slow expansion would result in significant crustal deformation (Bland et al., 2009).

Ganymede's diurnal stresses could also induce shear heating along existing fractures (Prockter et al., 2005). In the past, the existence of a thinner ice shell may have facilitated the cryovolcanic and tectonic resurfacing due to tidal stresses and shear heating. Diurnal stresses have possibly dominated the past due to Ganymede's higher orbital eccentricity (Cameron et al., 2016). However, as the current orbital eccentricity is low, NSR stresses likely dominate present-day shear stress failure mechanisms.

CHAPTER 2. DARDANUS SULCUS

Dardanus Sulcus, located at 13°W, 18°S, is known as region that appears as a NW-SE trending band of light terrain cross-cutting the surrounding dark terrain of Nicholson Regio (Fig. 5a). Damkina, a roughly 175 km wide dome crater, lies to the SE of the mapped area. Careful interpretation of Galileo imagery suggests consistent offset of the Dardanus Sulcus region of roughly 45 km along a NE-SW trending fault of approximately 150 km length. This region has not been analyzed in detail to test that it is a true lateral offset.

Detailed digital mapping of this region identified eight units with similar morphology (Fig. 5b). Unit 1 (oldest) is the heavily cratered dark terrain of the Nicholson Regio. Label a indicates the NE-SW oriented fault, which offsets the grooved terrains of units 2 and 3. En echelon structures can be identified in unit 2 (label b), indicating left-lateral shear. Unit 4 is interpreted to be the southern extension of unit 3, as they seem to have comparable appearance and spacing of their grooved terrain. Unit 5 is oriented differently and has a less organized structure than units 2 to 4. Units 7 and 8 have similar orientation and appearance, but their relationship is unclear.

Rose diagrams of the dark terrain indicate a generally NW-N trend (Fig. 5c). The younger terrain trends NE while the intermediately aged units trend NW. We can conclude two main stages of deformation of the light terrain: Stage 1 is the NE-SW extension of the oldest of the bright terrain units 2-4, and stage 2 is the right-lateral shear motion of units 2 and 3 (Fig. 5d). It is unclear where unit 6 should be placed in the tectonic history of Dardanus Sulcus. It has a similar orientation to units 2-4 and crosscuts unit 5, but could very well be the youngest unit of an additional period of deformation. Unit 8 is interpreted to be a younger extensional feature than units 2-4 and could have formed during stage 2.

It is important to note that the resolution of the Galileo images is lower for Dardanus Sulcus (750 m/pixel) than for the other regions we mapped and studied (generally <200 m/pixel) (Pappalardo et al, 2004). Future imaging missions will be able to fill in the present gaps in data and interpretation.

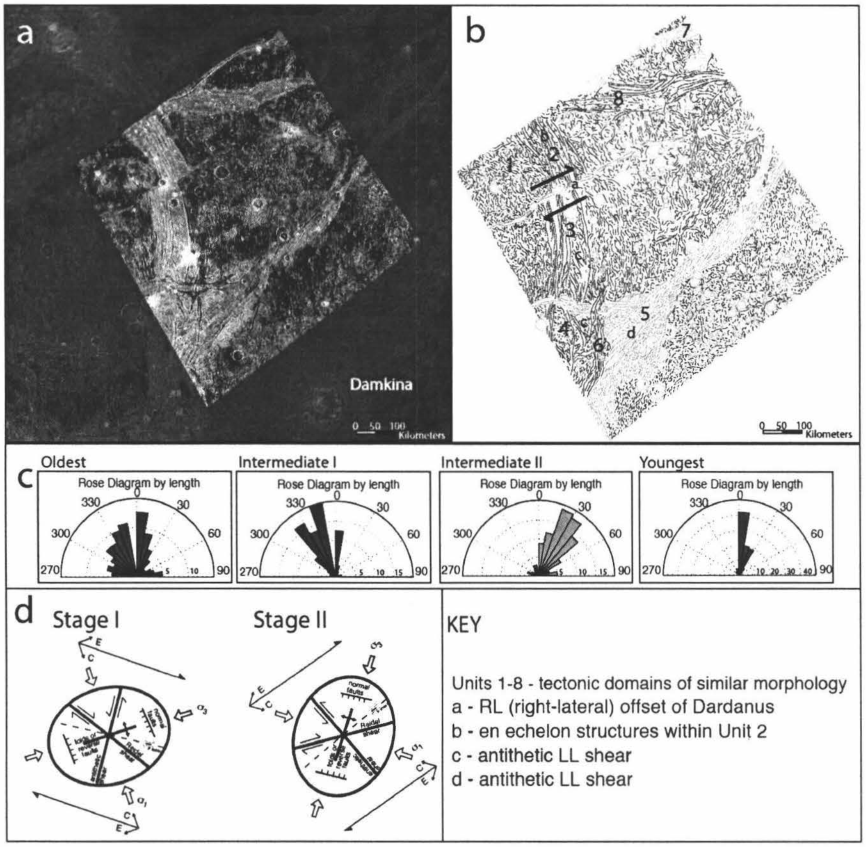


Figure 5
Dardanus Sulcus (a) Voyager background imagery underlying Galileo high-resolution imagery, (b) digitization, (c) rose diagrams (data restricted to northern hemisphere), and (d) diagrammatic ellipses. (Cameron et al., 2017b)

CHAPTER 3. METHODS

3.1 Mapping

For this study, Galileo image mosaics were originally processed in USGS ISIS (Integrated Software for Imagers and Spectrometers) (Becker et al., 2001) . After the mosaics were georeferenced and projected in cylindrical map projection in ArcGIS, we meticulously digitized interpretations of lineaments for eight regions containing high-resolution data. Additional image processing details for these mapping efforts can be found in Cameron et al. (2017b). Craters were mapped using a reference size for each dataset, representing the smallest crater to be considered for mapping. All images were mapped as consistently as possible but attention was focused on identifying strike-slip indicators such as en echelon, strained craters and offsets. A full description of these mapping results is provided in Cameron et al. (2017b) and will be synthesized into a global database for future use.

For use in GPlates, we used the global mosaic of Ganymede prepared by the USGS Astrogeology Science Center using the ISIS 2 image processing and cartographic system with a resolution of 20 km/pixel for gap fill to approximately 400 m/pixel and moderate viewing and sun angles for topography and albedo. The final map was scaled up to 1 km/pixel and merged with a monochrome base mosaic. The color of the mosaic was subsequently enhanced in Adobe Photoshop. We then imported the global mosaic into ArcGIS and georeferenced our high-resolution mosaic of Dardanus Sulcus onto the map (Fig. 6). We selected control points on individual pixels, making pixel measurements of their locations and correcting for geometric distortions.

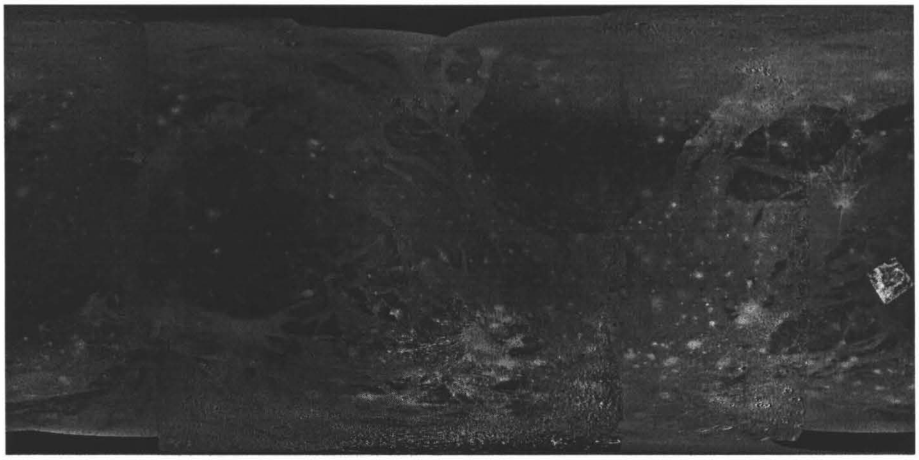


Figure 6
Global mosaic of Ganymede prepared for import into GPlates for spherical projection. Dardanus Sulcus is on the right of the map, appearing brighter than the base map.

3.2 GPlates

GPlates is an open-source freely available software (www.gplates.com) that can use georeferenced spacecraft images to map tectonic plate boundaries as polygon features. GPlates permits the use of these polygons to clip out image fragments and move them interactively to line up features within a spherical projection. The software is able to calculate the rotation poles that are necessary to describe this motion on a sphere from the original plate positions to the currently observed position. Finally, GPlates can animate the plate movements to demonstrate motion paths over time. While GPlates has been optimized to reconstruct tectonic plate motions on Earth (Cannon et al., 2014), it has recently been used to reconstruct regions on Europa (Collins et al., 2016; Rezza et al., 2017). However, it has never been used on Ganymede before.

In GPlates, the default is set to the 3-D Orthographic Globe view using an orthographic-view projection commonly seen in commercial design software, where the lines of projection are parallel. GPlates also supports a variety of 2-D map projection views including the rectangular, Mercator, Mollweide and Robinson projections that unwrap the globe onto a 2-D plane (Cannon et al., 2014).

We infer the offset at Dardanus Sulcus to represent the boundary between at least 2 conceptual ice plates that shifted laterally over time. Animated motion along Dardanus can help constrain the magnitude of possible motions, as the software will not let two plates pass through one another. GPlates also allows for multi-stage reconstruction since plates can be given different poles of motion for different time periods. After linking the image mosaic and the plate boundaries in GPlates, the plates are interactively moved and rotated to align with older features. During the interactive reconstruction, GPlates calculates a database of Euler poles to quantify past motions.

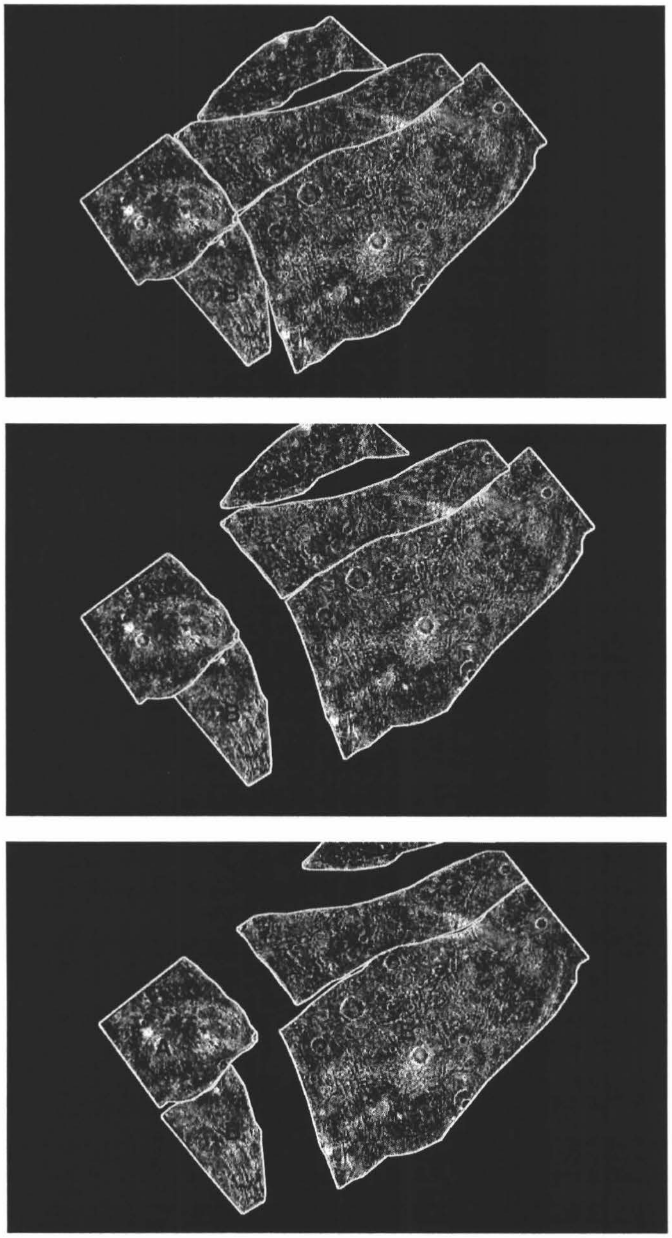
CHAPTER 4. RESULTS

For this study, we focused on Dardanus Sulcus, which we analyzed in detail to test that it is a true lateral offset. We mapped the region and performed an interactive reconstruction of the inferred offset area using GPlates to test the hypothesis of large-scale strike-slip offset and evaluate the regional history. We subdivided the surface along evident tectonic features until we arrived at a set of polygonal areas where coherent sets of older features could be aligned.

Because the imaging data for Dardanus Sulcus is of a lower resolution than the other regions, it was only possible to divide the region into five general plates, as detailed features were hard to identify. The region in the south of the Dardanus-spanning mosaic was omitted at this time because it is very complex with overlapping, crosscutting and interwoven light terrain features and hence a detailed preliminary analysis of the region did not generate a clear sequence of events. Future high-resolution imagery will be able to provide more insight into this area.

Possible plate boundaries were defined along pre-existing groups of features that were offset or truncated by newer ridges or bands (Fig. 7). As the primary mapping process revealed a sequence of age relationships (Fig. 5), our method was to was sequentially reconstructed the development of Dardanus Sulcus back through time. The older dark terrain was aligned after reconstructing the spreading of the ice, the forming of light terrain and the main offset (Fig. 8).

Figure 7
View of Dardanus Sulcus in GPlates with plate boundaries in current configuration.



(a) Phase 3

(b) Phase 2

(c) Phase 1

igure 8
Overview of Dardanus Sulcus during reconstruction. Yellow lines show the margins of mobile plates. Sequence of events: (a) preliminary stage (Phase 3), (b) intermediate stage (Phase 2), (c) current configuration (Phase 1).

Figure 8 shows the time sequence of plate motion and possible extensional events in the reconstruction to the current structure. GPlates requires the plates to move with respect to an anchored plate, which was assumed to be plate B in this analysis. Because of the right-lateral offset and extension, the reconstruction for the movements of plates D and E required multiple stages. During the interactive reconstruction, GPlates computed the Euler poles for the past motions (Table 1). This data is useful for any later or additional reconstruction of the region.

Phase 1 (Fig. 8c) for the reconstruction moved the offset and the extension along the offset back into an aligned position with plates A and D moving. Phase 2 (Fig. 8b) marked the completed extensional phase, with plates A and B as well as C, D and E fixed together, forming the light terrain between them. Phase 3 (Fig. 8a) is the completed preliminary terrain where all plates are joined.

Plate ID		Rotation Pole latitude	Rotation Pole longitude	Rotation magnitude
B	fixed	0.00	0.00	0.00
A	Phase 1	7.08	-24.02	4.32
D	Phase 1	42.24	6.38	-1.94
D	Phase 2	35.36	2.50	-2.55
E	Phase 2	11.86	-14.69	-0.19
C	Phase 3	37.47	2.54	-11.38
D	Phase 3	45.75	13.90	-4.16
E	Phase 3	-15.32	-34.50	2.59

Table 1
Rotation poles of the reconstructed plates. Plate B used as reference (anchored) plate. Phases indicate timing of plate movement.

CHAPTER 5. DISCUSSION

5.1 Plate Characteristics

Possible plate boundaries were defined along pre-existing groups of features that were offset or truncated by newer material. The older dark terrain was aligned after reconstructing the extension of the ice, the forming of light terrain and the main offset. Because of the lower image resolution of Dardanus Sulcus, more detailed features were hard to classify. The reconstruction shows that the plates appear to behave rigidly, but some plate margins did not line up effortlessly and most likely contain microplates.

Diurnal and NSR tidal stresses at Dardanus Sulcus predict a right-lateral sense of slip (Fig. 9), which is in concurrence with the observations made from the Galileo imagery and analysis of strike-slip indicators (Burkhard et al., 2015; Cameron et al, 2016). Results from stress modeling suggest that shear failure for Dardanus Sulcus is possible to a depth of 1-2 km for low friction (μ_f = 0.2) and high friction (μ_f = 0.6) cases (Cameron et al., 2016; 2017a).

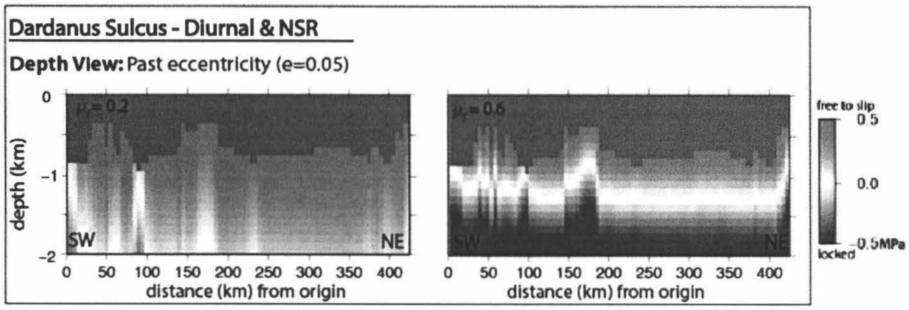


Figure 9
Coulomb failure stresses due to combined diurnal and NSR stress mechanisms for Dardanus Sulcus. Gray segments represent shallow regions of high tensile stress not subject to Coulomb failure. Coulomb stresses are presented as a function of depth for a past high eccentricity scenario. (Cameron et al., 2016)

From crater density measurements, we can estimate that dark terrain is >4 Gyr old (Zahnle et al., 2003). But because crater densities on neighboring Callisto are higher, Ganymede's surface is most likely not primordial (Shoemaker and Wolfe, 1982). Light terrain was likely emplaced between 400 Myr and 4 Gyr ago (Zahnle et al., 2003). As the thickness of the ice shell is unknown, spreading rates are difficult to quantify. Shearing rates are also not known, however, we can calculate an estimated shear velocity of 0.315 mm/year using strain rates provided by Collins et al (1998) and Nimmo et al (2002) and infer that it would take ~143 Myr for a 45 km offset to occur at Dardanus.

5.2 Evolutionary Sequence

As we can infer right-lateral offset and extension at Dardanus Sulcus, the reconstruction for the movements of plates requires multiple stages. During the interactive reconstruction, GPlates computed the Euler poles for the past motions, which are useful for any later or additional reconstruction of the region. The terrain has a right-lateral offset of 45 km, with a extension across the grooved terrain spanning roughly ~100 km. From the preliminary mapping analysis and the GPlates reconstruction, we can conclude that the offset is most likely the youngest tectonic feature in this region. As there are no strained craters present on this offset, we can infer that the plate movement must have occurred earlier in Ganymede's history.

CHAPTER 6. CONCLUSIONS AND FUTURE WORK

Interpretation of Galileo imagery suggests consistent offset of the Dardanus Sulcus region of roughly 45 km along a NE-SW trending fault of approximately 150 km length, appearing bright against the dark terrain. We performed a detailed mapping study of this region and used the GPlates software package to model hypothesized plate motions of Dardanus Sulcus on a sphere while conserving the original Galileo images in their original geographic locations. We were able to conclude that the offset is most likely the youngest tectonic feature in this region and it is clear evidence for strike-slip tectonism on Ganymede. The generated Euler poles will be useful for any extended or additional reconstruction of the region.

By investigating the potential evolutionary sequence of strike-slip structures, we gain an improved representation of the structural and evolutionary history of the deformation of Ganymede's large-scale strike-slip offsets. Through combining our previous work on Ganymede, we seek to advance our knowledge of the structural and evolutionary history of Ganymede through the visualization of available image data.

Here, we investigate and document strike-slip tectonics on Ganymede by visually presenting the deformation mechanisms acting on its surface. This work is directly relevant to NASA's Outer Planets Research Program in enhancing the scientific return from the Galileo and Voyager missions by continuing the analysis of their respective data sets through broadening scientific participation. This research is especially relevant in view of the JUpiter ICy moons Explorer (JUICE), the first large-class mission in ESA's Cosmic Vision 2015-2025 program planned for launch in 2022 and arrival at Jupiter in 2030. It will spend at least three years observing Jupiter as well Ganymede, Callisto and Europa and will eventually go into orbit around Ganymede, a first in Solar System exploration (ESA, 2017). As strike-slip tectonism appears to be an integral part of the grooved terrain process, future work will focus on examining structurally more complex regions and how the deformation has affected the global surface of Ganymede.

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