TIDALLY-DRIVEN STRIKE-SLIP FAILURE MECHANICS ON GANYMEDE. M.E. Cameron[1], B.R. Smith-Konter[1], R.T. Pappalardo[2], G. Collins[3], and F. Nimmo[4], [1]University of Texas at El Paso, Department of Geological Sciences, 500 W. University, El Paso, TX 79968, mecameron@miners.utep.edu, [2]Jet Propulsion Laboratory, California Institute of Technology, M/S 321-560, Pasadena, CA 91109, [3]Wheaton College, Phyiscs and Astronomy Department, Norton, MA 02766, [4]University of California Santa Cruz, Department of Earth and Planetary Sciences, Santa Cruz, CA 95064.

Introduction: Manifestations of strike-slip faulting have been documented on Ganymede and strike-slip tectonism may be important to the structural development of Ganymede's surface and in the transition from dark to light (grooved) materials [1]. Moreover, it seems likely that a past episode of high eccentricity [2] may have played a key role in Ganymede's tectonic history [3]. To better understand the role of tidal stress sources and implications for faulting on Ganymede, we investigate the relationship between shear and normal stresses at key strike-slip features. In this study, we target Dardanus Sulcus, a ~45 km of right-lateral offset along a NE–SW trending fault (~150 km in length) that appears bright against dark terrain. We quantitatively model current and past shear failure of faults as related to non-synchronous (NSR) stress along with diurnal stresses (which may have had a significant role during a past high-eccentricity era). Our preliminary results suggest that tidal stresses, under particular circumstances, can be sufficient to induce shear failure and generate the strike-slip offsets inferred at Dardanus.

Tidal Stress Modeling: To calculate diurnal and NSR tidal stresses on Ganymede, we utilize numerical code SatStress [4], adopting two end-member models: (1) Ganymede today (present-day eccentricity e = 0.0013), and (2) Ganymede in the past (using a conservative past high eccentricity e = 0.05). For both models, we assume the following parameters: ice shear modulus μ = 3.5 GPa, ice Poisson ratio ν = 0.33, gravity g = 1.428 m/s^2, ice density ρ = 1000 kg/m^3, satellite radius r = 2631 km, satellite mass m = 1.482 x 10^{23} kg, semi-major axis a = 1.07 x 10^6 km. When accounting for NSR stress, we assume steady-state rotation of a viscoelastic ice shell of viscosity ~10^{22} Pa s and rotation period 0.14 Ma (as in [4]). For the Ganymede today model, we adopt parameters appropriate to a spherically symmetric ice shell of thickness 150 km (its uppermost 10 km being cold stiff ice), underlain by a 40 km global subsurface ocean: we compute degree-two diurnal-period Love numbers h_2 = 1.43 and l_2 = 0.36, and NSR-period Love numbers h_2 = 1.96 and l_2 = 0.51. For a past (warmer) Ganymede model, we assume the ice has thickness 100 km (its uppermost 2 km being cold stiff ice), underlain by a 140 km global subsurface ocean: we compute degree-two diurnal-period Love numbers h_2 = 1.44 and l_2 = 0.38, and NSR-period Love numbers h_2 = 1.95 and l_2 = 0.51. We resolve the stress tensor components calculated by SatStress onto discrete fault segments of specified orientation, deriving both normal (σ_n) and shear (τ_s) stress components [5,6].

To assess shear failure at Dardanus Sulcus, we adopt a model based on the Coulomb failure criterion [7]. This model balances stresses that encourage and resist the motion of a fault, simultaneously accounting for both normal and shear tidal stresses, the coefficient of friction of ice (μ_f), and additional stress at depth due to the overburden pressure. In this model, tidal shear stresses drive strike-slip motions, while normal stresses control a fault's frictional resistance to failure. To model this behavior, we calculate Coulomb stress $\tau_c = |\tau_s| - \mu_f(\sigma_n + \rho g z)$, where $\rho g z$ is the overburden pressure (z is the vertical depth of the fault plane). The sign of the overburden stress is taken to be positive, while the normal tidal stress is assumed positive when in compression and negative when in tension. The sign of the shear stress, positive for right-lateral, negative for left-lateral, becomes important when inferring the direction of slip once the failure conditions are met. According to this model, shear failure will occur on optimally oriented fault segments when the shear stress exceeds the frictional resistance of the fault. Negative Coulomb stress implies a locked fault, while positive stress implies conditions supporting fault slip in horizontal shear. We assume brittle failure down to ~2 km depth, consistent with models of extensional instability in forming Ganymede's grooved terrain at observed topographic wavelengths [8,9].

Results: We investigate shear failure feasibility at Dardanus Sulcus both today and in the past, both as subject to diurnal stresses alone and for a combined diurnal + NSR stress regime. Love numbers are found to be similar for the present and past Ganymede structures that we assume. Thus, the primary difference in our two end-member models is the significant change in Ganymede's eccentricity, manifested as increased diurnal stress magnitude in the past Ganymede model.

To demonstrate Coulomb failure potential at Dardanus Sulcus, we assume an example parameter set that could potentially support strike-slip faulting: μ_f = 0.3 and observation depth z = 1.6 km. In this example, shear failure from diurnal tidal stresses alone is never achieved, either today or in the past, because the relatively large overburden stress (~2.3 MPa) dominates the frictional stress and cannot be overcome by the peak shear diurnal stress amplitudes (~1 kPa today, and ~20 kPa in the past). Neither present-day nor past eccentricities on Ganymede provide conditions for strike-slip faulting subject diurnal tidal stresses alone.

For shear failure to occur on Ganymede, tidal shear stress magnitudes must be on the order of the overburden pressure, which even at shallow depths (~1 km), is at least 1.4 MPa. Although diurnal tidal deformation cannot provide this large stress, an additional secular stress source potentially could. For example, NSR can provide stresses of one to several MPa for ~1° of NSR as traditionally parameterized [10,11], or by steady-state rotation of a viscoelastic ice shell of viscosity ~10^{22} Pa s and period ~ 10^4–10^5 yr in the [4] parameterization. In Figure 1, we show that NSR dominates diurnal stress magnitude and sign for the present or past scenarios, swamping much of the diurnal signal. At Dardanus Sulcus, shear stress (~0.4 MPa) is always right-lateral and normal stress (~1.1 MPa) is always tensile. Application of the Coulomb failure criterion shows that faults could succumb to right-lateral shear failure (the observed sense at Dardanus) throughout the orbital cycle today or in the past.

For present-day Ganymede, continuous right-lateral faulting (i.e., fault creep) is possible at z = 1.6 km depth for μ_f = 0.3. For past high-eccentricity, under otherwise similar conditions, diurnal stress effects become large enough that right-lateral strike-slip faulting is possible during specific "slip windows" of the diurnal cycle, while the fault becomes locked during other portions of the cycle. For this example, Dardanus Sulcus could slip in a right-lateral sense from perijove to orbital position ~ 75°, followed by a locked state, with resumed right-lateral slip from orbital position 250° around to perijove.

Conclusions: For Ganymede's Dardanus Sulcus, we consider tidal stress scenarios for both present (0.0013) and possible past high (~0.05) eccentricity. Diurnal stress alone cannot drive strike-slip motion in either scenario. Today, NSR shear stress resolved along the Dardanus fault is sufficient to induce continuous creep along strike-slip faults to ~1.4 km depth for μ_f ~0.3. For past high eccentricity, NSR + diurnal stress could have driven continuous creep or lock-slip fault motion, depending on the parameters assumed. Diurnal stress would have modulated NSR stress by ~100 kPa through Ganymede's tidal cycle. This implies that diurnal stressing might have induced shear heating and tidal walking mechanisms in the past.

Future work will be aimed at (1) investigating alternative secular stress mechanisms (true polar wander and internal differentiation) and (2) comparing the global distribution of strike-slip faults and any patterns that emerge—notably in the sense of right- and left-lateral shear inferred—to global-scale predictions of strike-slip shear sense on Ganymede from leading models of grooved terrain formation.

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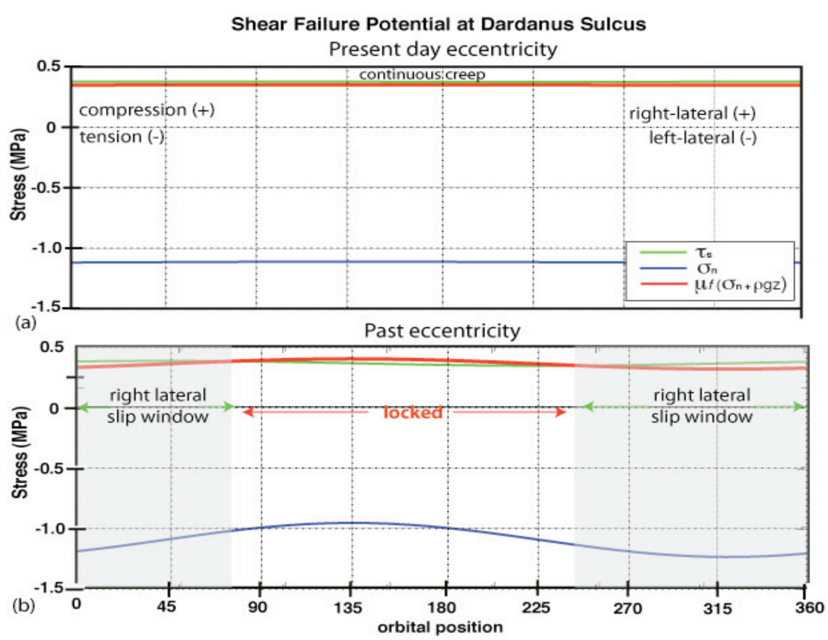

Figure 1. Diurnal + NSR stress and the Coulomb failure criterion at Dardanus Sulcus. (a) Present-day Ganymede (e = 0.0013) (b) Past high-eccentricity Ganymede (e = 0.05). The frictional stress (which is largely dominated by the overburden (~300 kPa), mimics the pattern of the normal tidal stress curve but is damped in amplitude by μ_f. Right-lateral shear failure will occur when the shear stress is greater than the frictional stress, which is manifested as continuous creep in (a), and windows of locking and slipping (gray shaded windows) in (b).