SHEAR MADNESS: MODELING STRIKE-SLIP FAULT EVOLUTION ON EUROPA. N. P. Hammond[1], G. C. Collins[2], J. C. Goodman[2], C. C. Walker[3], and C. McCarthy[4], [1]College of the Holy Cross, 1 College Street, Worcester MA (nhammond@holycross.edu), [2]Wheaton College of Massachusetts, [3]Woods Hole Oceanographic Institute, [4]Lamont-Doherty Earth Observatory of Columbia University.

Summary: Cyclic slip from diurnal tides can cause substantial shear heating along Europa's strike-slip faults. As the temperature increases, regions of partial melt can be generated and the fault zone then weakens enough to enable permanent slip to accumulate. Stresses from non-synchronous rotation can increase the failure depth of faults and allow significant fault slip and shear heating to occur even at high (>0.5) ice coefficients of friction.

Introduction: Many strike-slip faults have been observed on Europa, often along double ridges [1,2]. Shear heating along faults has been proposed as a mechanism for building double ridges [3,4] through the generation of thermal buoyancy and localized melting.

Do faults on Europa slide fast enough to generate melt? Previous shear heating models have imposed the sliding rate as a boundary condition [3,4]. Our study takes a different approach and uses the resolved tidal stress as a boundary condition. We then calculate the sliding and shear heating rate of faults on Europa that occur in response to these resolved stresses. We can therefore make specific predictions about how shear heating rates vary across Europa's surface for a given driving stress, fault location and fault orientation.

Model: We use a fault mechanics model to calculate the magnitude of cyclic-slip along faults in response to the diurnal tide. We calculate the local diurnal stress field from [5, Appendix B], and determine the resolved shear and normal stresses acting on the fault based on the fault orientation [6]. The depth of frictional failure is then determined based on a Mohr-Coulomb failure criterion. Once the depth of the fault is known, we use an elastic-half space model to determine the cyclic displacement between fault walls [7]. The magnitude of the displacement depends on the depth of the fault, the shear stress magnitude and the shear modulus of the fault zone.

Previously we found that cyclic-slip magnitudes of up to 1 meter per orbit were possible if the fault zone is weak and the coefficient of friction of ice is low [8]. However, if additional long-term driving stresses are acting on the fault, such as from non-synchronous rotation (NSR), the additional resolved stresses may increase the frictional failure depth and allow faults to slide farther, even if the ice shell has a higher coefficient of friction. We therefore calculate local stresses from NSR [9], for rotation periods between 10^5 – 10^6 years, and allow these to influence the frictional failure depth.

We calculate the thermal evolution of the fault zone with a two-dimensional finite difference model, including frictional heating along the fault. The magnitude of this frictional heating is based on the cyclic-slip magnitude calculated from the fault mechanics model. We use a nominal ice shell thickness of 10 km and a thermal diffusivity for ice of 10^{-6} m^2/s, however temperature dependent ice properties and various ice shell thicknesses will be tested in future work.

As the fault zone warms, the viscosity of the shear zone reduces and permanent fault slip begin to accumulate. Our thermal evolution model is therefore coupled with a fault zone evolution model which calculates permanent slip rates (Figure 1). We apply a long-term shear stress at the side of the model (away from the fault), and have a mixed boundary condition below the fault (free-slip above the frictional failure depth, and locked below). We then use of our finite difference model to calculate the along-strike accumulated slip rate, which is influenced by the evolving viscosity structure of the shear zone. We calculate ice viscosity based on the cumulative flow law of [10] and using an ice grain size of 1 mm.

Example Results: Figure 2 shows the temperature and slip evolution of a fault on Europa located at 77.8ºS, 121.7º W. We include NSR stresses for a rotation rate of ~10^5 years, which causes a resolved shear stress of ~300 kPa. This example uses an ice coefficient of friction of μ= 0.5, appropriate for low temperature ice sliding at low velocities [11]. Frictional heating from cyclic-slip begins to heat the fault, which is large enough to create a small zone of near-surface melting, but at first the overall viscosity of the shear zone is too high for permanent slip to occur. As the fault zone continually warms, the viscosity of the shear zone drops and the permanent slip rate beings to increase. Viscous dissipation increases as the permanent slip rate increases, causing a positive feedback that progressively weakens the fault zone and increases the slip rate. We find, in this case, that ~2.5 km of slip occurs after 100 kyr, enough to explain the observed offset.

Melting, Feedbacks and Future Work: If shear heating can create zones of near-surface melt, it could have massive implications for Europa's habitability and geologic evolution. Frictionally generated melts could be a potential source for plumes, and if melts migrate down toward the subsurface ocean, they could deliver oxidants and create favorable redox gradients for aquatic life [12]. However, complex feedbacks exist between the generation of eutectic melts, frictional heating and melt migration [13]. Future work will focus on incorporating the latest laboratory experiments on the frictional behavior of water ice/salt mixtures [14]. We will also investigate how quickly frictionally generated melts migrate via porous flow and channelized flow through fracture networks [15].

Overall we find that when diurnal stresses combine with larger sources of stress (NSR), shear heating could play a significant role on Europa through the generation of near-surface melts and by influencing the accumulated slip rates of strike-slip faults. Our study will investigate whether there is a correlation between the predicted magnitude of shear heating on certain faults and fault morphology. We will also attempt to constrain what driving sources are necessary to explain observed lateral offsets along Europa's faults.

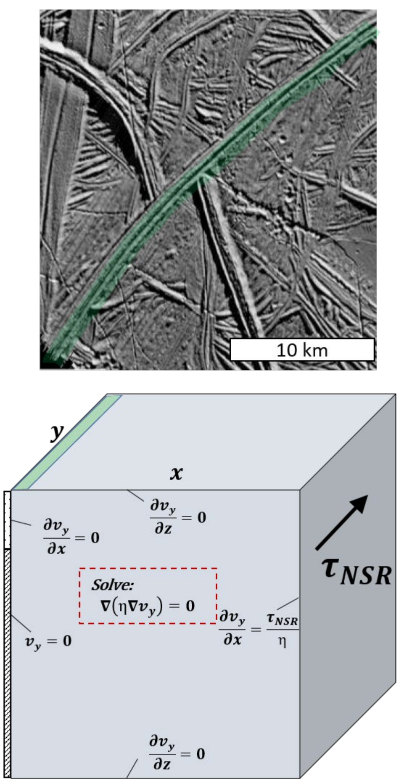

Figure 1: *(top) An example of a strike-slip offset along a double ridge on Europa, located at 78.8 S, 121.7 W. (bottom) A schematic showing our fault-zone evolution model which calculates the accumlated slip-rate* v_y *based on the resolved stresses from non-synchronous rotation and the viscosity structure of the fault zone.*

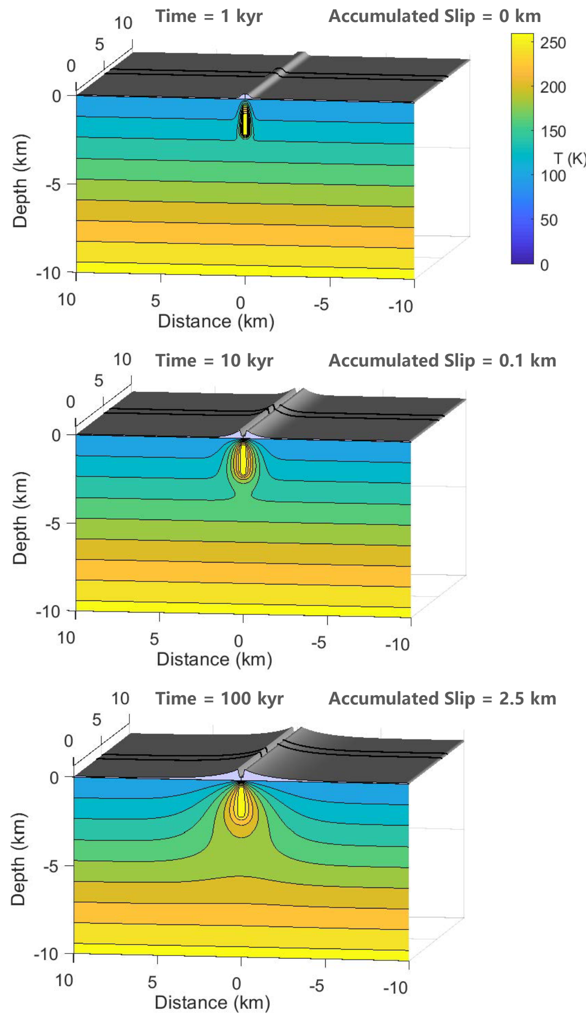

Figure 2: *Example of the progressive thermal evolution and coupled accumulated fault slip for the fault shown in figure 1. Before the fault zone warms, the viscosity of the shear zone is too high to allow permanent slip to occur. Thermal bouyancy and volume changes from meltng help generated double ridge like topography.*

References:

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