DEEP FAULTING, STRESS RELEASE, AND MOUNTAIN FORMATION ON IO. Michael T. Bland and William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for Space Sciences, Washington University in St Louis, MO 63130 (mbland@levee.wustl.edu).

Overview: A majority of the mountains on Io are tectonic in origin, consisting of tilted or upthrust blocks. Mountain formation is likely related to the prolific volcanism on the satellite, as global compressive stresses result from the continual burial and subsidence of the surface [1,2]. Here we show, using simple finite element models, that such "subsidence stresses" result in deep-seated thrust faulting that propagates upward to the surface, forming the principal mountain thrust block. Significantly, fault formation modifies the compressive stress field, inducing extensional stress in the near surface that might permit pathways for magma assent, and reducing the overall compressive stress throughout the lithosphere.

Mountain Formation on Io: Despite Io's extreme thermal emission, the presence of large tectonic mountains indicates it maintains a thick lithosphere. Io's interior is thus likely cooled advectively by voluminous localized volcanic eruptions in a so-called "heat pipe" model [3]. Such global magma emplacement forces the preexisting surface layers to subside, leading to a global state of compression within the lithosphere [1,2]. This compressional stress state is likely modified by thermoelastic stresses due to regional variations in volcanic activity as well [4]. Despite the overall compressive state of the lithosphere, extensional tectonic features are observed on Io's surface [e.g., 5-9], and the eruption of magma requires pathways of tensile (or at least low compressive) stress. Thus, the globally compressive stress field must be modified locally to permit such deformation.

Simulating Deep Compression: We show, using finite element modeling of deep thrust fault formation, and upward propagation, that stress release and limited surface extension is a natural kinematic complement to mountain formation on Io. We use the Lagrangian finite element code Tekton to simulate deep compression on the moon. The code is viscoelastic-plastic and includes strain weakening and non-associative plasticity [10,11]. We assume the dry diabase rheology of [12] and a vertical temperature profile from the analytical calculations of [4]. The geometry is simplified from the actual situation on Io, but we directly mimic the style of compression due to the global inward advection of volcanic layers by imposing a constant horizontal velocity boundary condition that increases linearly with depth. The horizontal strain rate is zero at the surface and 10^{-15} s^{-1} at the base of the lithosphere (consistent with typical resurfacing rates [4]).

Results and Discussion: A typical simulation is shown in Fig. 1 for a 25 km deep x 80 km wide domain. At 0.6% basal strain only limited brittle failure has occurred and the differential strain field imposed has caused modest up-warping of the surface. By 0.7% strain, a "fault" has formed deep in the lithosphere and begun to propagate upward, accommodating strain in a narrow zone of brittle failure. By 0.9% strain a splay fault has developed that reaches the surface, and by 1.2% basal strain substantial surface displacement (corresponding to what will become an uplifted mountain block) has occurred. At this point significant brittle failure has occurred in the near surface *over* the thrust fault itself. This is a region of extension that naturally results from the development of the thrust fault, due both to flexural arching and the horizontal motion of the hanging wall once the fault daylights. The extensional failure reaches down more than 5 km along a series of steeply dipping faults or shear planes, and would correspond to regions of incipient rifting or small-scale graben formation.

Figure 2 shows the horizontally averaged differential stress as a function of depth as compression occurs. Before the onset of faulting the stresses are compressional throughout the lithosphere, increasing with depth until dropping to zero near the asthenospheric boundary due to viscous creep (i.e., a classic strength envelope). Fault formation reduces the compressive stress such that by 1.2% basal strain the averaged stresses in the top five kilometers of the domain are weakly tensile. Thus, despite the global compressive stress regime, deeply formed thrust faults on Io naturally give rise to regions of surface tensile stress and extensional strain. Once an orogenic fault forms, further regional subsidence or thermal expansion strain should be accommodated by continued fault motion, giving rise to the spectacular mountains we see today.

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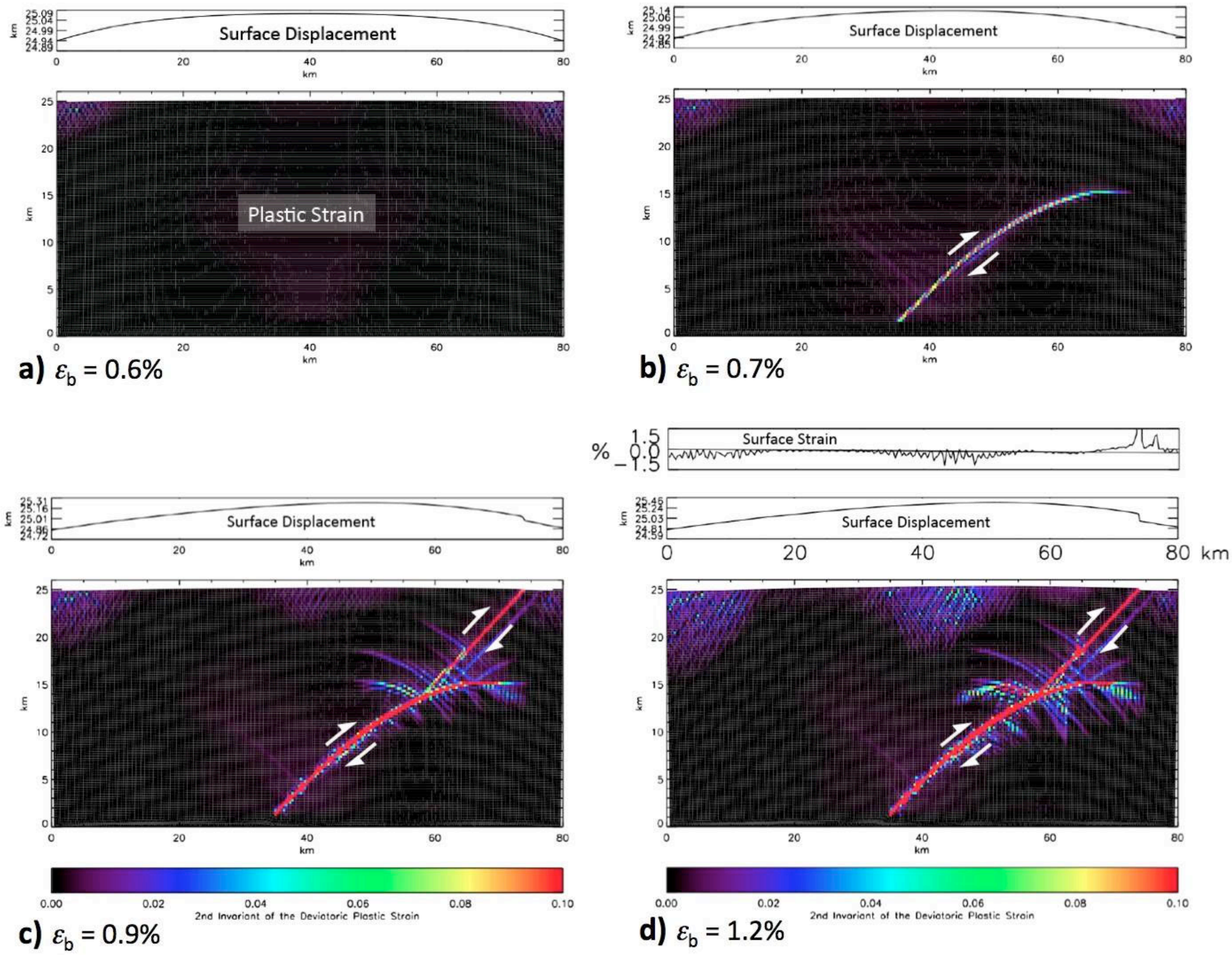

Figure 1: The surface displacement (top) and distribution of plastic strain (a proxy for brittle failure) within the lithosphere at (a) 0.6%, (b) 0.7%, (c) 0.9% and (d) 1.2% basal compressive strain (ε_b). Arrows indicate the direction of relative 'fault' motion. Panel (d) also shows the horizontal strain in the elements at the surface of the domain.

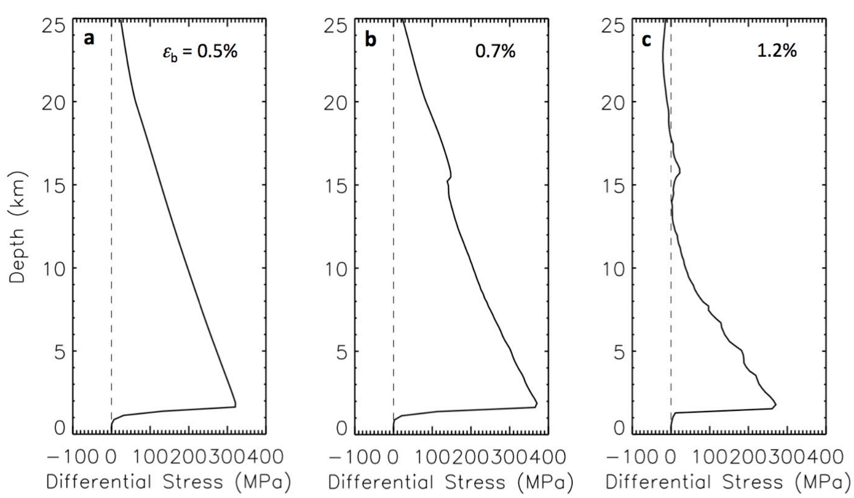

Figure 2: Differential stress (σ_{xx}-σ_{zz}, compression positive) within the crust before (a) during (b) and after (c) fault formation for the simulation shown in Fig. 1. Note that differential stresses decline to zero at the base of the crust in all panels due to viscous creep [2,4].