LITHOSPHERIC RECYCLING ON IO: THE ROLE OF DELAMINATION. W. L. Jaeger[1], L. P. Keszthelyi[2] and E. P. Turtle[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, jaeger@lpl.arizona.edu, [2]Astrogeology Team, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001.

Introduction: Jupiter's moon Io is both volcanically and tectonically active, but it does not appear to recycle its lithosphere by plate tectonics. Instead, Io seems to displace lithospheric material primarily vertically rather than horizontally. Igneous processes remove magma from the interior of Io and add it to the lithosphere either as surface flows or as intrusive bodies. This transfer of material from Io's interior to its exterior drives lithospheric subsidence and, in doing so, causes a net compression of the lithosphere. The mechanics of subsidence, coupled with the associated thermal stress, is thought to drive the uplift of many ionian mountains via reverse faulting [1, 2]. If lithospheric volume is conserved, the amount of material added to the lithosphere by igneous processes must be equivalent to the amount that is destroyed. High eruptive temperatures derived from NIMS and SSI data suggest mafic to ultramafic volcanism on Io [e.g., 3, 4], and global similarities in the SSI spectra of recently emplaced lava flows indicate that lava compositions are broadly uniform [5]. These data suggest that Io does not have a chemically evolved lithosphere [6]; therefore, it seems inevitable that lithospheric recycling must involve a wholesale reincorporation of material into the asthenosphere. This study attempts to better understand the mechanism(s) by which Io recycles its lithosphere and to place new constraints on lithospheric thickness.

Recycling Mechanisms: There are at least 3 possible ways of recycling the ionian lithosphere: thermal erosion, plucking and delamination; any of these processes could function independently or simultaneously. Thermal erosion can define the base of the lithosphere as the critical depth where the timescale for internal convection becomes shorter than that for subsidence (i.e., material will be laterally displaced by convection faster than it is depressed by subsidence). Plucking, on the other hand, will occur if irregularities in the base of the lithosphere allow material to be torn off by frictional forces and entrained in the convecting asthenosphere. Plucking can remove material ranging from large blocks to small clasts. Delamination, the detachment and sinking of the lowermost lithosphere, may occur on Io if (a) there is a density inversion within the lithosphere, and (b) a means of locally decoupling the buoyant upper lithosphere from the dense lowermost part exists. On Earth, delamination plays an important role in the recycling of continental lithosphere. In the following section we examine its importance for Io.

Delamination: As mentioned above, Io's lithosphere is likely to be comprised of mafic to ultramafic lavas, making it compositionally dense. An estimated thermal profile shows that the lithosphere should also be largely cold, and therefore thermally dense, with conduction heating only the bottom few kilometers [7]. Conversely, the asthenosphere should have a relatively low density. Lava temperatures in excess of 1600 K [3] strongly suggest a large degree of partial melting. This is consistent with, and perhaps required by, Io's pressure gradient (Figure 1). While the pressure at the top of the asthenosphere is lithostatic, much greater pressures are achieved in the overlying rock. Under the condition of uniform global subsidence, compressive stress accumulates with depth such that at the base of a 30 km-thick lithosphere the stress is ~450 MPa, or ~3 times lithostatic pressure. For this arbitrary (but reasonable) lithospheric thickness, magma generated in the asthenosphere cannot ascend through the lithosphere without "pressure freezing" unless it is hot enough to remain largely molten at ~450 MPa.

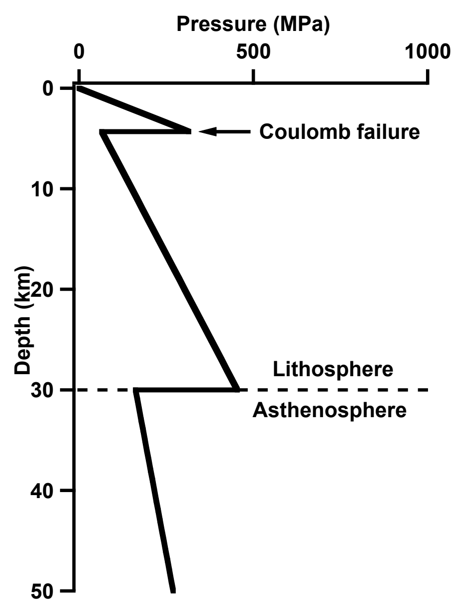

Figure 1. Pressure gradient through Io's upper 50 km as computed for an arbitrary (but plausible) lithospheric thickness of 30 km. Descending from the surface, pressure accumulates rapidly until the point of Coulomb failure then behaves according to Byerlee's Law for frictional sliding. Pressure in the asthenosphere is lithostatic.

The subsidence and compaction of cold, dense lavas over a hot interior are likely to set up a density inversion. In order to quantify the density profile of Io's lithosphere, its composition must be estimated. Io's large core and low density suggest a bulk composition matching that of L or LL chonrdites [8]. For the purpose of this abstract, we derive an asthenosphere composition from an L chondrite bulk composition and we assume a temperature of 1750 K (50% partial melt) for the top of the asthenosphere. This temperature is >100 K less than that of the hottest lavas reported on Io [4]. Results for a broader range of temperatures and compositions will be presented. Using the lithospheric density profile of [9] (which assumes a value for rock density that is consistent with our composition and temperature) we find a density inversion in the lithosphere at a depth of ~20 km. This suggests that delamination is possible for a lithosphere thicker than ~20 km provided that a weak zone exists along which the lower lithosphere can detach. Volatiles interbedded with silicate lavas may provide such an interface.

On Earth, both compressive and tensile tectonics can trigger decoupling that leads to delamination. Io, though devoid of plate tectonics, has an abundance of compressive faulting as evidenced by its numerous mountains [1, 2]. Subsidence causes compressive stress to increase more rapidly at greater depths, therefore reverse faults will propagate down faster than up. As a result, the faults that uplift mountains may well transect the entire lithosphere. In many ways, these faults are similar to terrestrial collisional plate margins, although the analogy is limited (e.g., typical aspect ratios are quite different). Nonetheless, compressive faulting on Io may weaken the base of the descending slab in a manner similar to collisional tectonics on Earth thereby facilitating delamination.

Constraining Lithospheric Thickness: The density inversion in Io's lithosphere can be used to place an upper limit on lithospheric thickness in 2 ways: (a) by determining a critical thickness at which the lithosphere is unstable because its mean density exceeds that of the upper asthenosphere, and (b) by computing the thickness at which the stress exerted by the negatively buoyant lower lithosphere will cause tensile failure even without the presence of a weak zone. Using the first technique and assuming the composition and melt fraction described above, we find that a lithospheric thickness greater than ~50 km is unstable. Using the second technique and making the same assumptions, we find that tensile failure will occur at a similar lithospheric thickness, ~55 km.

Conclusions: The preliminary results of this study suggest that (1) a density inversion in the ionian lithosphere is likely, (2) a mechanism for decoupling the buoyant upper lithosphere from the dense lower lithosphere exists, and therefore (3) delamination may be an important mechanism for recycling Io's lithosphere. This could have observable surface effects such as isostatic rebound and could allow for wholesale recycling of the lithosphere without melting its base in situ. However, significant melting in the upper asthenosphere may be necessary for magma to rise through the elevated pressure in the lower lithosphere. We describe two new techniques for placing an upper limit on lithospheric thickness, but before a hard constraint can be placed, it is necessary to explore a broader range of parameter space.

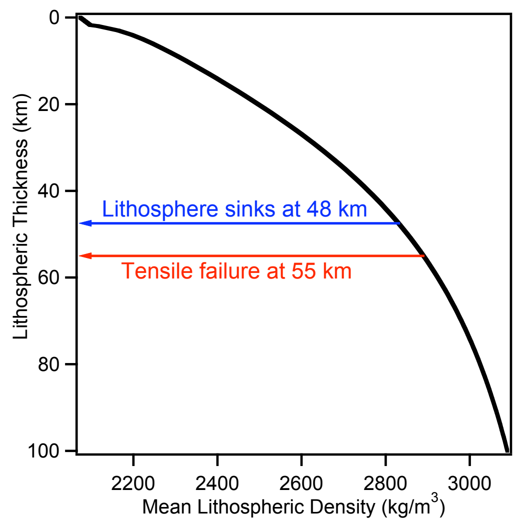

Figure 2. Mean density of the lithosphere (derived using the technique of [9]) as a function of lithospheric thickness. Assuming an L chondrite bulk composition for Io and a temperature of 1750 K (~50% melt) in the upper asthenosphere, the mean density of the lithosphere will exceed that at the top of the asthenosphere at a thickness of 48 km. If lithospheric thickness exceeds 55 km, stress induced by the negative buoyancy of its base will cause tensile failure, assuming the value for the tensile strength of gabbro and basalt [10].

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