STRAIN LOCALIZATION AND DYNAMIC WEAKENING WITHIN RAYLEIGH-TAYLOR INSTABILITIES: INSIGHTS FROM A TERRESTRIAL INSTABILITY AND IMPLICATIONS FOR LUNAR CUMULATE MANTLE OVERTURN. N. Dygert[1] , R. E. Bernard[2], W. M. Behr[3], [1]University of Tennessee, Knoxville, Knoxville, Tennessee (ndygert1@utk.edu); [2]Amherset College, Amherst Massachusetts, [3]Swiss Federal Institute of Technology (ETH), Zürich, Switzerland.

Introduction: Rayleigh-Taylor (R-T) instabilities in planetary interiors, also known as "drips" or diapirs are thought to redistribute mass in the Moon, Mars, Earth and elsewhere [1-3]. Such instabilities are associated with anomalous magmatism and heat flux, changes in topography, and perturbed seismic velocity structure. In planetary mantles, they are driven by unstable density stratification [4], mantle convection associated with secular cooling and radioactive decay [5], and other mechanisms such as tidal heating [6] and plate tectonic cycling [7]. Despite the importance of R-T instabilities for the thermochemical evolution of the Moon, Earth and planets, little is known about how stress and strain are partitioned among relatively strong and weak phases within R-T instabilities, largely because instabilities that form in the mantle are almost impossible to sample directly. Because the effective viscosity contrast between a R-T instability and surrounding mantle is a key parameter in determining spatial scales and timescales over which R-T instabilities develop [8], insights into strain partitioning and strain localization (and their implications for viscosity) are critically needed to model R-T instabilities in a meaningful way. Improved dynamical models may provide new insights into the evolution of lunar and planetary interiors.

The Great Basin Drip: A downwelling R-T instability beneath central Nevada has been inferred based on seismic body wave anomalies with a circular expression in map view that extend at least 500km into the mantle and circular shear wave splitting anomalies whose magnitude scales with proximity to the feature (Fig. 1) [9]. Located directly above the inferred instability is a low heat flow anomaly, a topographic high and the prominent and isolated intraplate Lunar Crater volcanic field, which produces abundant alkali basalt-hosted mantle xenoliths.

Lunar Crater Mantle Xenoliths: Lunar Crater mantle xenoliths are dunites, wehrlites, harzburgites and lherzolites with olivine Mg#s of 86-92 (100×Mg/Mg+Fe, in moles) and light REE enrichment in clinopyroxene consistent with derivation from the mantle lithosphere (rather than the asthenosphere) [3]. The xenoliths are remarkable in that they universally record high (~1200°C) equilibration temperatures, much higher then almost all other localities in the Basin and Range, requiring derivation from the very base of the mantle lithosphere. About 15% of the xenoliths exhibit microstructural evidence of a recent deformation event (Fig. 2). [3] interpreted the equilibration temperatures, deformation history, and proximity of the volcanic field to the geophysical anomalies as suggesting the xenoliths are derived directly from the Great Basin Drip.

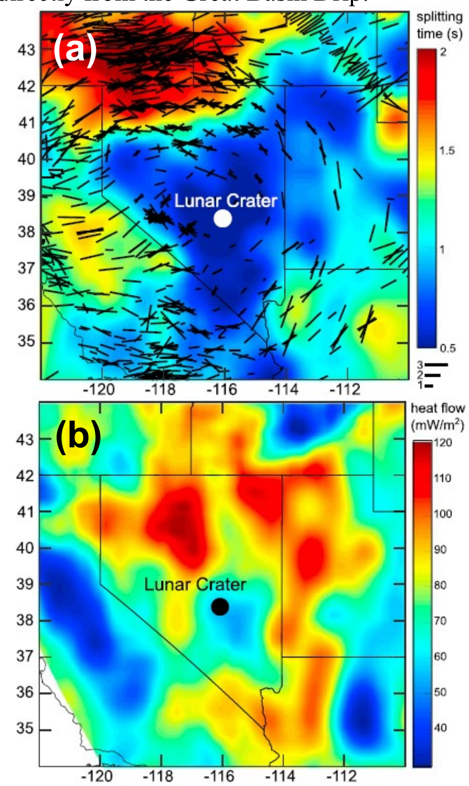

Figure 1. (a) Shear wave splitting anomalies exhibit a circular pattern around Lunar Crater volcanic field. (b) Lunar Crater volcanic field is associated with anomalously low heat flow. Modified from [3].

Deformation Conditions: Paleostresses were constrained by applying a grain size piezometer [10] to recrystallized olivine grains. Among all mylonites (n=13), average grain sizes are 82μm, implying dynamic recrystallization at ~50 MPa. Olivine water contents of 4 to 12 ppm H_2O were measured by secondary ion mass spectrometry. Deformation temperatures were constrained by applying a fast resetting Ca-in-olivine thermometer [11] to recrystallized olivine grains in clinopyroxene-bearing samples. The lack of Ca zonation in recrystallized olivines directly adjacent to clinopyroxenes implies the thermometer records the deformation temperature (~1200°C).

Implications for strain partitioning: Using olivine flow laws [12], strain rates can be calculated using measured water contents, temperatures and paleostresses.

Strain rates are 2×10^{-9} to 4×10^{-7}/s, implying low effective viscosities of 8.9×10^{13} to 1.4×10^{16} Pa·s. Assuming reasonable instability sinking rates (~10 to 0.1m/y), the effective width of the strained region within the instability (perhaps the neck) can be estimated to be ~0.1 to 100m depending on wet or dry conditions (Fig. 3). This highlights the importance of strain localization for accommodating deformation within R-T instabilities, and the importance of dynamic weakening in establishing mantle viscosity. We note that all the mylonitic Lunar Crater xenoliths have low pyroxene abundances and Mg#s, implying strain is preferentially partitioned into the weakest rocks in the mantle lithosphere, consistent with phase mixing theory [13].

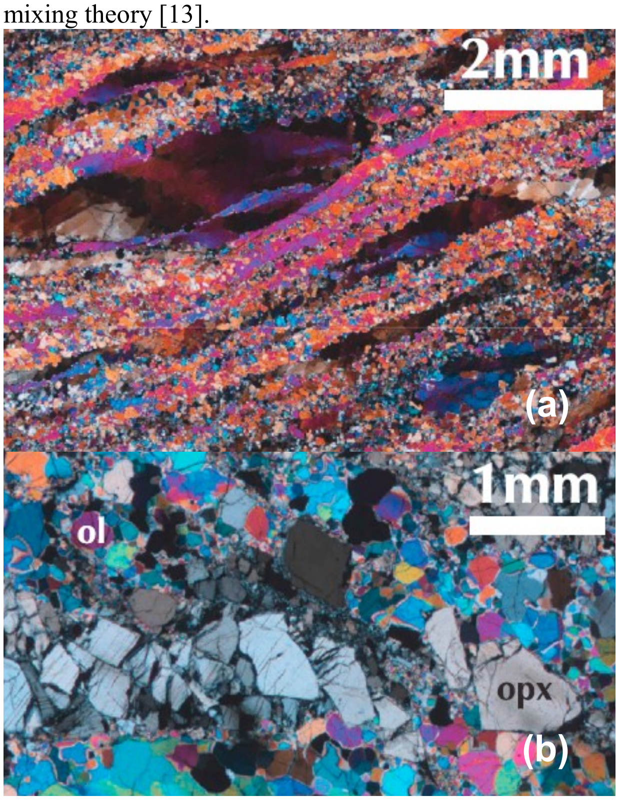

Figure 2. Cross polarized light micrographs of a mylonitic dunite (a) and harzburgite (b). Olivine porphyroclasts exhibit subgrain formation and interpenetrating grain boundaries consistent with dynamic recrystallization and deformation by dislocation creep. Orthopyroxene exhibit fracturing and domino offsets within the foliation plane demonstrating brittle deformation and high viscous yield strength relative to olivine at the deformation conditions. Modified from [3].

Implications for Lunar Cumulate Mantle Overturn: In the Moon, cumulate mantle overturn is thought to be driven by gravitational instability produced by crystallization of ilmenite as a late liquidus phase of the magma ocean. Recent work shows that ilmenite is exceptionally weak relative to olivine [14]. The present study suggests that R-T instabilities that develop in the lunar mantle will be accommodated by dominant partitioning of strain into weak ilmenite, even at dilute ilmenite volume fractions. Dynamic weakening in strain accommodating ilmenite-bearing shear zones, perhaps at the margins of lunar R-T instabilities, may significantly reduce effective viscosity, driving low degree (perhaps hemispheric) cumulate mantle overturn [1].

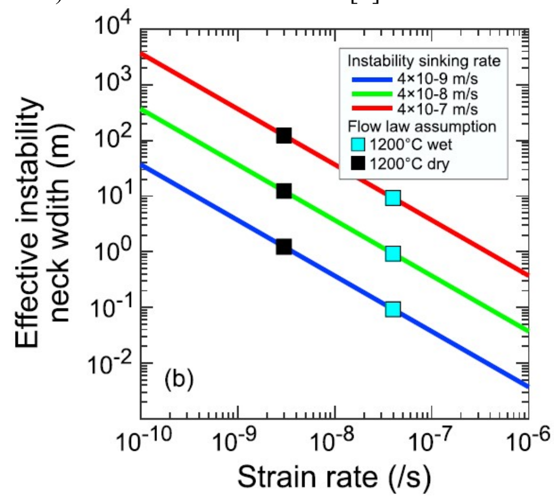

Figure 3. Effective width of strained region within the R-T instability assuming sinking rates corresponding to ~0.1-10 m/y. Black and cyan squares correspond to assumption of dry and wet conditions, respectively. Modified from [3].

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