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Scale-dependent response from the invariant rescaling of stress in a self-gravitating thermomechanical Earth

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It is widely known that gravitation can be accounted for via general relativity in a four-dimensional manifold called spacetime. A direct corollary of this is that the observable characteristics of any self-gravitating body in space are closely tied to its 'rheology' – how stress and deformation are related to one another. The large-scale/long-term response of terrestrial planets to loading is arguably dissipative, which can be modeled using purely viscous rheology. Evidence for this includes Earth's flattened ellipsoidal configuration, the likely result of self-gravity and rotation. On the other hand, the small scale, short-term response of solid earth materials is arguably conservative, which can be modeled using

purely elastic rheology. Evidence for this includes the propagation of shear waves throughout the crust and mantle. These general observations, combined with long-term creep and attenuation of seismic signals at the longest wavelengths, seems to suggest that networks of springs, dash pots, and sliding masses, although vogue, comprise only one possible family of an otherwise infinite number of rheological models. The response of solid earth materials to loading is a scale-dependent process and involves both elasticity (strain-energy storage) and viscosity (energy dissipation).

Tectonic processes are controlled by regional stratification, lithology, thermal structure, fluid content, metamorphic reactions, and deformation rates, many aspects of which are inherited through geological time. Clearly, topography and igneous activity on terrestrial planets are closely allied phenomena, consistent with global and regional isostatic balance demonstrated through gravity-topography analysis. It is reasonable to conclude that crustal stratification and igneous activity are inherent features of the

Earth system, which must be predicted by any self-consistent model.

We have assumed that solid earth rheology can be modeled using the differential grade-2 (DG-2) material (Patton & Watkinson 2010, 2013). In consequence we find that all solid earth materials exhibit some degree of strength at the smallest scales, i.e. the ability to support a finite normal stress difference, and that deformation is dominated by dislocations. In contrast, solid-state deformation at large scales tends to be distributed, bordering on 'flow'. Ultimately, for DG-2 materials, we have demonstrated that toroidal motion of the lithosphere is governed by the diharmonic equation, while poloidal motion is driven by non-isotropic pressure gradients (Patton, submitted 2013). These conclusions have important implications for the estimation of the long-term rheological properties of

the lithosphere based on the coarse-graining of laboratory rock-mechanics data. Specifically, work with DG-2 materials suggests that a diffusion-like mechanism is in play throughout the crust and upper mantle, and that the structure of this important region of the Earth can be profitably understood in terms of thermomechanical competence