The Lithospheric Geoid: Implications for Continental Structure and the Intraplate Stress Field.

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ABSTRACT

It has long been recognized that the motion of the mechanically rigid lithospheric plates of the earth are the surface expression of large-scale convection in the mantle. It is also accepted that the stresses driving plate motion are an amalgam of the basal tractions associated with this convection and long-wavelength density variations within the plates themselves. Parsing the relative contribution from these two sources to the geodynamics of the lithosphere continues to be an important topic of plate dynamics research. Because geoid anomalies are directly related to the local dipole moment of the density-depth distribution, they provide an ideal method for evaluating density variations within the lithosphere and the associated tectonic stresses. The main challenge with this approach is isolating the lithospheric geoid contribution from the full geoid (which is dominated by sources in the lower mantle). We address this issue by using a high-pass spherical harmonic filtering of the EGM2008-WGS84 geoid (which is complete to spherical harmonic degree and order 2159), with a cosine taper between degree 6 to 9 and between terms 355 and 360 to produce a “lithospheric” geoid. In this study we focus on tectonic implications of the lithospheric geoid in three areas: 1) mid-ocean ridges and the cooling oceanic lithospheric, where we find that previous estimates of a geoid anomaly of 10-15 meters associated with ridges to be valid; 2) passive continental margins where we have evaluated over 150 margin-transects spaced roughly every three degrees. The global average geoid anomaly associated with the transition from old oceanic lithosphere to the continent was found to be 6-9 meters and appears to be insensitive to a range of geoid filtering degrees and orders; and 3) continental regions which are characterized by both elevated geoid anomalies (e.g., the Western U.S.) and geoid lows (e.g., the Congo Basin in Africa). These geoid anomalies have important implications for our understanding of the dynamics of plate tectonics. The 10-15 m geoid highs associated globally with ridges are consistent with a net force
of ~2 to 3x10^{12} \text{N/m} due to “ridge push.” Converting gradients in the oceanic “lithospheric” geoid produce net torques on the plates consistent with this magnitude of “ridge push.” The 6-9 meter geoid step up across passive continental margins is consistent with a reduction of the ridge force acting on the continents, as evidenced by increased strike slip and normal deformation on the continents compared to oceanic lithosphere. The fact that such a small geoid step can affect tectonic style is evidence that even relatively small forces, like the ridge force compared to the negative buoyancy of subducted lithosphere, can be important in plate dynamics. Our evaluation of the lithospheric geoid confirms the near equivalence of the gravitational potential energy (GPE) of typical continental lithosphere and the mid-ocean ridges, which suggests that information about density distributions within the lithosphere is communicated at the plate-scale through the transmission of intraplate stresses through the lithospheric plates. This notion is substantiated by evaluating the predicted intraplate stresses (computed using a finite-element analysis of a lithospheric shell under traction from the gravitational potential energy forces associated with the lithospheric geoid) in the African plate, which can be expected to best approximate the ambient lithospheric stress state given its unique plate boundary of being nearly completely surrounded by mid-ocean ridges. In general, the results presented support the notion of “active” (versus “passive”) tectonic plates where weak continental lithosphere facilitates dynamic plates tectonics.

INTRODUCTION

The relationship between the gravitational potential energy (GPE) associated with lithospheric density contrasts and the dynamics of lithospheric deformation is well established (Artyushkov, 1973; England and Houseman, 1988; Fleitout and Froidevaux, 1982, 1983; Frank, 1972; Houseman et al., 1981; Lister, 1975; Molnar and Tapponier, 1978; Ricard et al., 1984) and has important implications for understanding the source of tectonic stresses responsible for sedimentary basin development, mountain-building processes, and continental deformation (Naliboff et al., 2009; Naliboff et al., 2011). Initial