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# Spatial variations of effective elastic thickness of the lithosphere in Central America and surrounding regions

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ABSTRACT

As a proxy for long-term lithospheric strength, the effective elastic thickness ($T_e$) can be used to understand the relationship between lithospheric rheology and geodynamic evolution of complex tectonic settings. Here we present, for the first time, high-resolution maps of spatial variations of $T_e$ in Central America and surrounding regions from the analysis of the coherence between topography and Bouguer gravity anomaly using multitaper and wavelet methods. Regardless of the technical differences between the two methods, there is a good overall agreement in the spatial variations of $T_e$ recovered from both methods. Although absolute $T_e$ values can vary in both maps, the qualitative $T_e$ structure and location of the main $T_e$ gradients are very similar. The pattern of the $T_e$ variations in Central America and surrounding regions agrees well with the tectonic provinces in the region, and it is closely related to major tectonic boundaries, where the Middle American and Lesser Antilles subduction zones are characterized by a band of high $T_e$ on the downgoing slab seaward of the trenches. These high $T_e$ values are related to internal loads (and in the case of the southernmost tip of the Lesser Antilles subduction zone also associated with a large amount of sediments) and should be interpreted with caution. Finally, there is a relatively good correlation, despite some uncertainties, between surface heat flow and our $T_e$ results for the study area. These results suggest that although this area is geologically complex, the thermal state of the lithosphere has profound influence on its strength, such that $T_e$ is strongly governed by thermal structure.



## 1. Introduction

The knowledge of lateral variations in lithosphere strength can aid in understanding how surface deformation relates to deep Earth processes. As a proxy for long-term lithospheric strength, the effective elastic thickness of the lithosphere ($T_e$) corresponds to the thickness of an idealized elastic plate bending under the same applied loads (Watts, 2001), and is related to the integrated mechanical strength of the lithosphere (Burov and Diament, 1995). The knowledge of $T_e$ in different places provides a measurement of the spatial variation of the lithospheric strength, which is strongly controlled by local and regional conditions. Although $T_e$ does not represent an actual depth to the base of the mechanical lithosphere, its spatial variations reflect relative lateral variations in lithospheric mechanical thickness (see McNutt, 1984). Thus it can be used to understand the relationship between lithospheric rheology and geodynamic evolution of complex tectonic settings.

$T_e$ primarily depends on the thickness and structure of the crust, the composition of the crust and the lithospheric mantle, the degree of their coupling, the thermal state of the lithosphere, the state of stress, plate curvature, and the presence of melts, fluids and faults (e.g., Lowry and Smith, 1995; Burov and Diament, 1995; Lowry et al., 2000; Watts, 2001; Artemieva, 2011). The oceanic lithosphere generally behaves like a single mechanical layer due to the thin crust, which is usually coupled to the lithospheric mantle, and $T_e$ is to first order controlled by the thermal age of the lithosphere at the time of loading (Watts, 2001; Kalnins and Watts, 2009). By contrast, the thermal state and rheological behavior of the lithosphere in continental areas are largely a consequence of local conditions (e.g., Ranalli, 1997; Afonso and Ranalli, 2004; Bürgmann and Dresen, 2008; Hasterok and Chapman, 2011; Mareschal and Jaupart, 2013), such that there is a complex relationship between $T_e$ and its controlling parameters (Watts and Burov, 2003; Burov and Watts, 2006; Burov, 2011).

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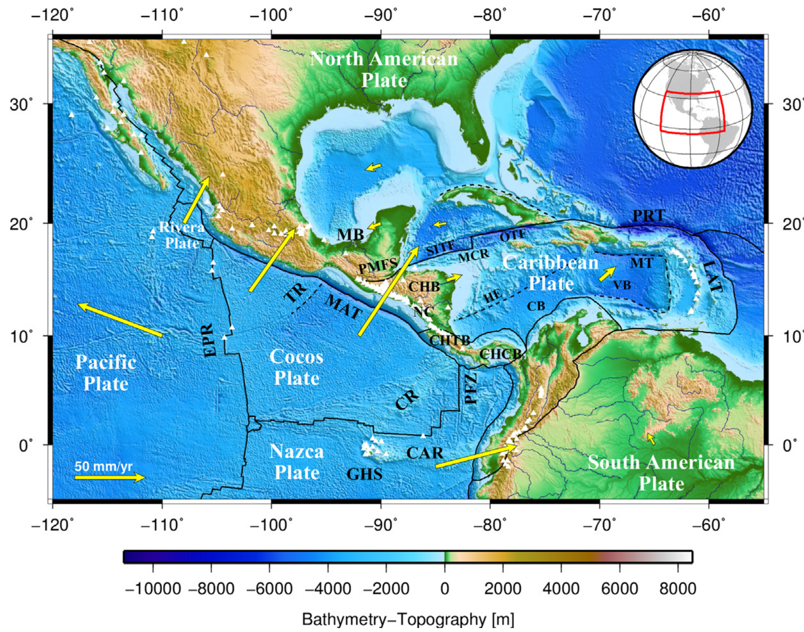


**Fig. 1.** Geotectonic setting of Central America and surrounding regions. Shaded relief image of bathymetry and topography is from ETOPO1 digital data (Amante and Eakins, 2009), and boundaries of lithospheric plates are based on the PB2002 model (Bird, 2003). Yellow arrows denote vectors of the plate motion from the MORVEL model (DeMets et al., 2010) with respect to the NNR reference frame as calculated at the given position with the Plate Motion Calculator (http://www.unavco.org/community_science/science-support/crustal_motion/dxdt/model.html). Triangles show the position of Holocene volcanoes (Siebert and Simkin, 2002). Abbreviations: CAR, Carnegie Ridge; CB, Colombian Basin; CHB, Chortis Block; CHCB, Chocó Block; CHTB, Chorotega Block; CR, Cocos Ridge; EPR, East Pacific Rise; GHS, Galápagos Hotspot; HE, Hess Escarpment; LAT, Lesser Antilles Trench; MAT, Middle America Trench; MB, Maya Block; MCR, Mid-Cayman Rise; MT, Muertos Trough; ND, Nicaraguan Depression; OTF, Oriente Transform Fault; PFZ, Panamá Fracture Zone; PMFS, Polochic–Motagua Fault System; PRT, Puerto Rico Trench; SITF, Swan Island Transform Fault; TR, Tehuantepec Ridge; VB, Venezuelan Basin. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In this study we present, for the first time, high-resolution maps of spatial variations of $T_e$ in Central America and surrounding regions from the analysis of the Bouguer coherence using both multitaper and wavelet methods. The Central America–Caribbean region is characterized by the interaction of six lithospheric plates (Fig. 1). The Caribbean plate moves eastward relative to its two neighboring plates, North and South America plates (DeMets et al., 2010), and its perimeter is characterized by a high variability and complexity of geodynamic and tectonic processes (e.g., Sykes et al., 1982; Ross and Scotese, 1988). Therefore, this area represents a good natural laboratory to study the spatial variations of $T_e$, test the response of spectral methods to different factors and geodynamic conditions, and examine relationships between surface deformation, lithospheric structure and mantle dynamics.

In the following sections we first introduce the methodology and data employed for estimating $T_e$. We then present our results and compare them to previous estimates of $T_e$ in the study area. Finally, we examine the relationships between $T_e$ with other proxies for lithospheric and sub-lithospheric structure to improve our knowledge of the long-term rheology and mechanical behavior of the lithosphere in the study area. We also discuss how the lithospheric structure derived from our $T_e$ analysis relates to surface deformation.

## 2. $T_e$ estimation by spectral methods

To estimate the effective elastic thickness we calculate the coherence function relating the topography and Bouguer anomaly, commonly known as Bouguer coherence, using multitaper and wavelet methods. This function gives information on the wavelength band over which topography and Bouguer anomaly are correlated. In the coherence deconvolution method of Forsyth (1985), $T_e$ is estimated by comparing the observed coherence curve with coherence functions predicted for a range of $T_e$ values. For each given $T_e$, we calculate via deconvolution the initial surface and subsurface loads and compensating deflections that generate a predicted topography and gravity that best fit the observed topography and gravity anomaly, and a predicted coherence that best fits the observed coherence (Forsyth, 1985). The $T_e$ value that minimizes the differences between the predicted and observed quantities is the optimal one for the analyzed area. The Bouguer coherence generally tends to zero at short wavelengths, where the topography is not compensated and loads are supported predominantly by the elastic strength of the lithosphere (Forsyth, 1985). At long wavelengths, the response to loading approaches the Airy limit and the coherence tends to one. The wavelengths at which the coherence rapidly increases from 0 to 1 depend on the effective elastic thickness of the lithosphere, such that when the lithosphere is weak and $T_e$ is small, local compensation for loading occurs at relatively shorter wavelengths and vice versa.

In this section we describe briefly the methodology and data employed to estimate $T_e$. For an extensive description of the methods, choice of parameters and biases in $T_e$ estimation, see Supplementary Material associated with the online version of this article.

### 2.1. Multitaper method

To recover spatial variations in $T_e$ we divide the analysis area into overlapping windows, such that in each window the coherence is calculated and inverted assuming a spatially constant $T_e$, moving the centre of each window 50 km for each new estimate. Calculation of the observed and predicted coherence involves transformation into the Fourier domain of the topography and Bouguer gravity anomaly to estimate their auto- and cross-power spectra. Because both data sets are non-periodic and finite, the Fourier transformation presents problems of frequency leakage (Thomson, 1982; Simons et al., 2000), resulting in estimated spectra that differ from the true spectra. To reduce leakage, the data are first multiplied by a set of orthogonal tapers in the space domain, the Fourier transform of the data-taper product taken for