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Review Article

Models of crustal thickness for South America from seismic refraction, receiver functions and surface wave tomography

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ABSTRACT

An extensive compilation of crustal thicknesses is used to develop crustal models in continental South America. We consider point crustal thicknesses from seismic refraction experiments, receiver function analyses, and surface-wave dispersion. Estimates of crustal thickness derived from gravity anomalies were only included along the continental shelf and in some areas of the Andes to fill large gaps in seismic coverage. Two crustal models were developed: A) by simple interpolation of the point estimates, and B) our preferred model, based on the same point estimates, interpolated with surface-wave tomography. Despite gaps in continental coverage, both models reveal interesting crustal thickness variations. In the Andean range, the crust reaches 75 km in Southern Peru and the Bolivian Altiplano, while crustal thicknesses seem to be close to the global continental average (~40 km) in Ecuador and southern Colombia (despite high elevations), and along the southern Andes of Chile–Argentina (elevation lower than 2000 m). In the stable continental platform the average thickness is 38 ± 5 km (1-st. deviation) and no systematic differences are observed among Archean–Paleoproterozoic cratons, NeoProterozoic fold belts, and low-altitude intracratonic sedimentary basins. An exception is the Borborema Province (NE Brazil) with crust ~30–35 km thick. Narrow belts surrounding the cratons are suggested in central Brazil, parallel to the eastern and southern border of the Amazon craton, and possibly along the TransBrasiliano Lineament continuing into the Chaco basin, where crust thinner than 35 km is observed. In the sub-Andean region, between the mid-plate cratons and the Andean cordillera, the crust tends to be thinner (~35 km) than the average crust in the stable platform, a feature possibly inherited from the old pre-Cambrian history of the continent. We expect that these crustal models will be useful for studies of isostasy, dynamic topography, and crustal evolution of the continent.

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1. Introduction

Mapping variations of crustal thickness in the continents have many important applications for the study of the continental crust and lithosphere. Besides giving information on the crustal evolution, degree of isostatic compensation (e.g., Sacek and Ussami, 2009), and intraplate stress patterns (e.g., Lithgow-Bertelloni and Guynn, 2004), crustal thickness estimates are essential for modeling wave-propagation in global and regional seismic studies (e.g., Hjörleifsdóttir and Ekstrom, 2010; Lebedev and van der Hilst, 2008), monitoring regional-scale seismicity (e.g. Ferreira et al., 2008), and for source discrimination in the framework of the Comprehensive Nuclear Test-Ban Treaty (e.g. Cormier and Anderson, 2004; Fan and Lay, 1998). In addition, models of crustal thickness variation can serve for developing surface corrections to investigate upper mantle structure through either body-wave or surface-wave tomography studies (e.g. Bastow et al., 2008; Park et al., 2008) and/or through the study of the Earth's normal-modes of vibration (e.g., Justowski et al., 2007; Mooney and Kaban, 2010). Also, the increasing use of shorter wavelengths in global seismic modeling requires correspondingly more accurate models of crustal thickness variation (e.g., Fichtner and Igel, 2008; Fichtner et al., 2009).

In spite of its importance, crustal thickness is still among the least known crustal properties of South America. Large areas of the continent, such as the Amazon craton and the Chaco basin in NE Argentina, are sparsely sampled and detailed information on crustal structure is lacking (e.g. van der Lee et al., 2001). The best known area is the Andean region, for which a number of passive and active seismic experiments have been carried out (e.g. ANCORP, 2003; Gans et al., 2011; McGlashan et al., 2008; Yuan et al., 2002) and detailed models of crustal structure have been developed by combining seismic data and gravity modeling in Venezuela (Niu et al., 2007) and South and Central Andes (Tassara and Echaurren, 2012). In addition, several temporary seismic experiments in NW Argentina and Chile have also mapped crustal structure over the region of flat-slab subduction (e.g. Calkins et al., 2006; Gans et al., 2011) and the Bolivian altiplano (e.g. Beck and Zandt, 2002; Beck et al., 1996; Swenson et al., 2000). In the tectonically stable part of the continent, the most comprehensive crustal thickness maps were produced by Feng et al. (2007) and Lloyd et al. (2010), through constrained tomographic inversion of surface-wave data. Those studies used both average epicenter-station 1D models and group velocities and incorporated local constraints on crustal thickness from independent receiver function studies and seismic refraction profiles. Some additional information based on isostatic assumptions was also included. Nonetheless, in spite of fitting seismic point constraints with a root mean square (RMS) deviation of about 3–4 km, these crustal thickness models still had errors around 10 km in areas without point constraints.

We have built on a previous compilation of seismic point constraints for crustal thickness in the Brazilian shield and adjacent regions (Assumpção et al., in press) to produce an enlarged compilation of 920 point constraints, 730 onshore and 190 offshore, for the whole of South America. To our knowledge, this is the most comprehensive compilation of seismic point constraints on crustal thicknesses for the continent. Previous continental-scale compilations of crustal thickness were performed during the development of global crustal thickness models, such as CRUST2.0 (Bassin et al., 2000), CRUST5.1 (Mooney et al., 1998), or the global compilation of Soller et al. (1982), but those studies had very sparse coverage in South America and/or focused on a single data type. Models CRUST5.1 and CRUST2.0, for instance, were based entirely on crustal thickness estimates from active-source profiling and ignored constraints on crustal thickness from passive-source studies. Soller et al. (1982) used both active-source profiling and surface-wave studies, but included just a few studies in the Andean region for South America leaving crustal thickness estimates for the majority of the continent as mere extrapolations (Tanimoto, 1995). Our dataset largely improves and updates the constraints provided in those earlier compilations.

Comparing the newly compiled set of seismic crustal thickness with the Bouguer Anomaly we derived an empirical relationship that is then used for predicting crustal thickness in areas where no seismic data is available (such as parts of the northern Andes and the continental shelf). We developed two types of models of crustal thickness variation for South America. The first type consists of an interpolation of the seismically-constrained and gravity-predicted crustal thicknesses, while the second type consists of an interpolation based on surface-wave studies. As expected, the addition of new point constraints improves the resolution of crustal thickness estimates in previously unsampled areas of the continent, such as Northern Andes (Ecuador, Colombia and Venezuela) and Northeastern Brazil (Borborema Province and northern part of the São Francisco craton) and the southern part of the Paraná basin. However, large portions of stable South America remain poorly sampled and predictions from our models within those regions could have significant errors (around 5–10 km). We hope that this study will motivate the deployment of temporary broadband experiments to fill in the gaps in our knowledge. Despite the largely unsampled areas, we show that derived maps of crustal thickness correlate with first order tectonic features of the continent and give new insights into the old geological control on the present-day crustal structure.

Finally, the point constraints compiled in this study have been utilized in the validation of an independent model of crustal thickness variation for South America based on satellite gravity (van der Meijde et al., 2013–submitted for publication).

2. Compilation of published crustal thickness data

We expanded the recent compilation of seismic crustal thicknesses for the Brazilian shield and adjacent regions (Assumpção et al., in press), which included 229 previous point constraints from Feng et al. (2007), 244 from Lloyd et al. (2010), 183 from Tassara and Echaurren (2012), and 200 from Pavão et al. (2012), to a total of 920 point constraints. Additional point constraints were incorporated for Venezuela (Niu et al., 2007; Schmitz et al., 2005), Central and Northern Andes (Dorbath et al., 1993; Robalino, 1977 (*apud* Feininger and Seguin, 1983; Ocola et al., 1975); Pacific offshore margin (Agudelo et al., 2009; Hussong et al., 1976; Meyer et al., 1976); Western Argentina (Gans et al., 2011), NE Argentina (Rosa et al., 2010), South Central Peru (Phillips et al., 2012), southern Puna (Bianchi et al., 2013), and Patagonia (Lawrence and Wiens, 2004). Point constraints developed in Assumpção et al. (in press) from receiver functions for 19 newly installed seismic stations in Brazil were also included.

The point constraints come from two different seismic data types: active source experiments (deep seismic refraction lines, or deep seismic reflection surveys) and receiver functions (see Fig. 1). Logically, point constraints from active-source profiling required sampling the seismic line at regular intervals. For 2D seismic refraction models, points were selected at every 50 km, on average; for old, 1D models,