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Thin crust beneath the Chaco-Paraná Basin by surface-wave tomography

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ABSTRACT

We present the results of surface-wave group velocity tomography for South America, using dispersion curves from a) regional earthquakes recorded at permanent and portable stations and b) inter-station cross-correlation of ambient noise for stations in and around the Paraná and Chaco-Paraná basins, achieving better path coverage and a more azimuthally uniform distribution. A 2D group velocity tomographic inversion, using two different smoothing criteria (first- and second-derivative smoothing) was performed in the period 10–150 s for the Rayleigh wave and 10–90 s for the Love wave, displayed improved resolution in northern Argentina and southern Brazil, compared with previous studies. A grid-search method was applied to estimate sediment, crustal thickness and upper mantle Sn velocity maps for the Chaco-Paraná basin. Our results obtained from a more complete dataset reveal an average crustal thickness for the Chaco-Paraná basin of about 35 km, reaching approximately 28–30 km beneath the northern region. S-wave velocities in the uppermost mantle are about 2% lower than IASP91 model, especially for the northern region, suggesting a shallower asthenosphere. These results are consistent with previous estimates, but are more robust because we used a larger dataset and tested different inversion constraints.

1. Introduction

The continental crust provides the most complete record of the geological history of the Earth, and the study of the deep crustal structure gives information on the geological and geodynamic evolution. The seismic structure of the crust and the uppermost mantle are fundamental constraints in understanding the tectonic evolution of an area and they can be studied through the analysis of surface wave dispersion. The S-wave seismic velocity profile, obtained with surface wave tomography, is helpful in revealing the nature of the crust.

Thin crust beneath the Chaco-Paraná basin (Fig. 1) had been suggested in some previous studies. Snoke and James (1997) found a rather shallow average Moho depth of 32 km and low upper-mantle S-wave velocities for the basin. In an E–W profile from the Andes, using receiver functions, Yuan et al. (2002) suggested that the Moho depth becomes even shallower (30 km) in the Chaco plain. Feng et al. (2007) estimated a Moho depth of 30 km in the central part of the basin as well as low velocities in the lithospheric mantle. Lloyd et al. (2010) also obtained a thin Moho (~30 km) in the northern Chaco-Paraná basin and the westernmost Paraná basin using basically the same data set of Feng et al. (2007). A ~35 km crustal thickness for CPUP station in Paraguay was computed by EARS (Earthscope Automated Receiver Survey, Crotwell and Owens, 2005). Chulick et al. (2013) found a Moho depth of 30 km for the central Chaco basin, increasing towards the north, based on a continental compilation of seismic data (deep refraction profiles and receiver functions). Recently, Assumpção et al. (2013) presented models of crustal thickness in South America using data mainly from receiver functions and surface-wave tomography. In the central part of the continent, in particular along the basins that make up the Andean foreland, they found average crustal thicknesses less than 35 km. The models of Assumpção et al. (2013) also used some estimates of crustal thickness from gravity models to fill in large areas not directly

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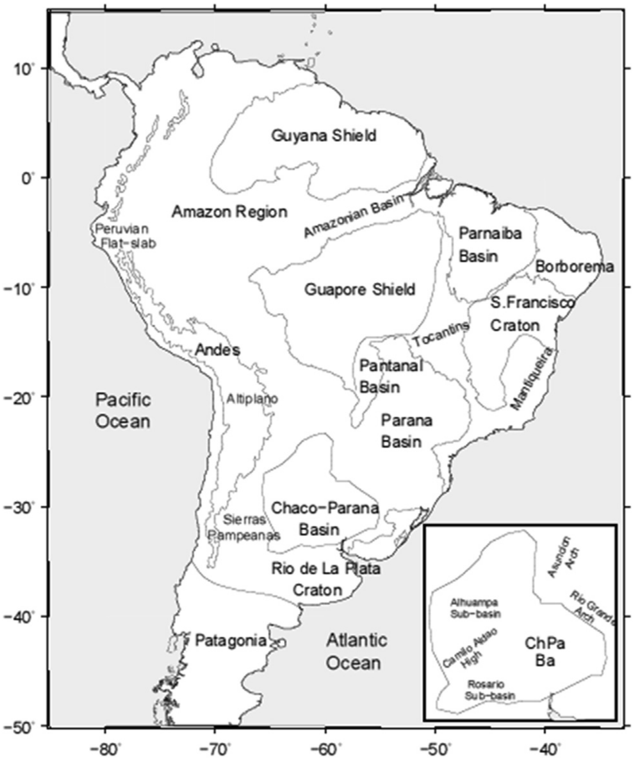

Fig. 1. Geotectonic map of South America.

sampled by receiver functions. Gravity data has been widely used to infer crustal thickness. For example Van der Meijde et al. (2013) and Dragone et al. (2014) inverted Bouguer anomalies and also obtained a thin crust along the sub-Andean basins. However, gravity inversions often assume a constant crust-mantle density contrast, which may not be justified. Again, lateral variations of crustal or upper mantle densities may cause artificial variations of crustal thicknesses when the constant density hypothesis is used. The thin crust in the tomographic models (Feng et al., 2007; Lloyd et al., 2010) was mainly based on surface waves as there are very few direct seismic measurements in the Chaco-Paraná basin. However, a common source of uncertainty in obtaining crustal thickness from surface-wave tomography (especially from dispersion curves) is the trade-off between crustal thickness and upper mantle velocity. A thin crust can result, in part, by compensation of a very low velocity anomaly in the lithospheric mantle. In addition, different smoothing criteria in the 2D tomography can result in different regionalized dispersion curves (i.e., the set of group velocities for each cell) and different 1D models.

In this work we improve the resolution of crustal images in the Chaco-Paraná basin, compared with previous inversions, using an expanded dataset of regional events recorded at different stations, as well as inter-station dispersion curves from ambient noise cross-correlation. Although our main interest is the Chaco-Paraná basin, we also present group velocity maps for the whole continent as they may be useful for other studies such as joint inversion of receiver functions and dispersion curves.

Earthquakes in and around South America were analyzed by multiple filtering to obtain the fundamental-mode group velocities in the period range 10–150 s for the Rayleigh wave and 10–90 s for the Love wave. For ambient noise correlation, we used periods from 10 to 40 s for both waves. We used different regularization criteria and smoothing parameters to test their influence in the derived crustal structure. The group velocity maps estimated for different periods correspond well to the tectonic structure throughout the continent and the spatial resolution was improved in the central and southeastern part, especially for the Chaco-Paraná basin, by the better seismic ray coverage. The new group velocity maps were then inverted to estimate crustal structure in the basin (sediment and crustal thicknesses, and Sn velocity). This two-step method of surface wave inversion is traditionally applied to regional continental-scale studies (e.g., Pasyanos et al., 2001; Feng et al., 2004; Vuan et al., 2005).

2. The Chaco-Paraná basin

The South American continent has evolved since the Archean by successive periods of gathering and dispersion of continental landmasses, which are expected to have left a permanent imprint in the lithosphere. Because of this evolution, several basins were formed in western Gondwana; one of them is the Chaco-Paraná basin, located in the southern and southwestern parts of the South American platform (Fig. 1). Its dimensions are not well defined, but it is most clearly developed mainly in northeast Argentina. It extends west from the narrow southern end of the Paraná basin of Brazil and it is separated from this basin through the Asuncion and Rio Grande Arches (Fig. 1, inset). It is bounded on the west by the Eastern Cordillera, on the east and northeast by the Brazilian Shield and on the south by the Río de La Plata craton. It is divided into two sub-basins separated by the Camilo Aldao High (Barredo and Stinco, 2010): the Rosario sub-basin in the southeast and the Alhuampa sub-basin in the northwest (Grahn, 2003). A multitude of depositional sequences, with marine and/or continental components are found in the basin whose borders were constantly reconfigured by tectonic activity.

The basin is apparently underlain by cratonic, Precambrian to early Paleozoic basement (Winn and Steinmetz, 1998). It contains Paleozoic strata, from the Early Silurian or Early Devonian, a thick Mesozoic to Tertiary clastic and volcanic section and a cover of Quaternary Cenozoic sediments, corresponding to distal foreland basin deposits (Ramos, 1999). This sedimentary package was deposited in a foreland basin for some authors (e.g.: McQuarrie et al., 2005; Prezzi et al., 2014), while for others, in a passive margin sag or intracratonic basin (e.g.: Winn and Steinmetz, 1998; Grahn, 2003; Limarino and Spalletti, 2006; Barredo and Stinco, 2010; Vitorello et al., 2011). The Chaco-Paraná province underwent several episodes of subsidence. Rifting within southwest Gondwana during the late Paleozoic resulted in northeast-oriented grabens and horsts in the region (Winn and Steinmetz, 1998). From the Late Carboniferous to the Early Cretaceous, it shares a common sedimentation history with the Paraná basin (Milani and Thomaz Filho, 2000), but it differs widely in the Cambro-Ordovician and Cenozoic sequences.

3. Data and dispersion measurements

Fundamental Love and Rayleigh waves recorded at different stations, including LPA (La Plata; Fig. 2a) from UNLP (National University of La Plata, Argentina) and stations from the GSN, GEOSCOPE and Brazilian networks, mainly in South America and a few in the surrounding ocean islands, were utilized for producing the tomography maps. Despite relatively high cultural noise levels at LPA (located in La Plata city, Argentina, 11 km from the coast), this station was important to improve the seismic path coverage in the region.

Earthquakes from NEIC and ISC catalogs, located in and around South America with magnitudes greater than 4.5 were selected. We analyzed more than 2060 records for LPA from 2006 to 2012, and