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New insights on regional tectonics and basement composition beneath the eastern Sierras Pampeanas (Argentine back-arc region) from seismological and gravity data

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ABSTRACT

The eastern Sierras Pampeanas (ESP) are the easternmost expression of a series of foreland uplifts in the Argentine back arc region (~30–34°S) and show spatial and temporal connections with the subduction of the Juan Fernández Ridge (JFR) under the South American plate. In order to get new insights on the mechanisms that control crustal regional tectonics, we computed teleseismic receiver functions (RF) and jointly invert them with Rayleigh-wave phase velocity dispersion curves. RFs allow resolving crustal thickness and intra crustal velocity variations with a good vertical resolution whereas surface wave information helps to constrain absolute seismic wave velocities.

Our seismic images have been combined with crustal density modeling in order to further investigate if the shear wave velocity structure obtained from the RF-SW joint inversion could explain the observed gravity variations. Our results show a crustal thickness varying from 35–40 km (east) to 45–50 km (west) with a Moho step at ~66°W. This step regionally presents a NW-SE orientation and is parallel to the trace at the surface of the Valle Fértil–La Huerta (VFLH) lineament (Cuyania-Pampia boundary). Our images also reveal the presence of a high wave velocity (high density) lower crust west of this Moho step, beneath the eastern Sierras Pampeanas (at 66–67°W). This observation suggests the east-dipping extension at depth of the VFLH structure and the underthrusting of the Cuyania lower crust under the Pampia terrane along this structure. Finally, we evidenced localized low velocity zones located at about 10 km beneath late Cenozoic volcanic fields (Pocho, Morro). We believe that these low velocity zones correspond to old magma chambers associated to the recent, slab flattening-related volcanism in the ESP.

1. Introduction and geological setting

Observations resulting from geological (Stauder, 1973; Ramos, 1988; Kay and Abbruzzi, 1996; Ramos et al., 2002) and geophysical investigations (Barazangi and Isacks, 1976; Cahill and Isacks, 1992; Anderson et al., 2007; Mulcahy et al., 2014) have produced constraints on along strike variations in the angle of subduction including the Chilean-Pampean flat slab segment (Fig. 1). The flat slab subduction has been related to the subduction of the Juan Fernandez Ridge (JFR), a submarine volcano chain located on top of the Nazca plate (Yáñez et al., 2002), as the geometry of the Nazca plate under the South American plate matches the projected orientation of the JFR.

At the surface, the Argentine back-arc region is characterized by three main structural units (Fig. 1). These units are the Pampia terrane to the east, where the eastern Sierras Pampeanas (ESP) are located, the Cuyania terrane in the middle, containing the Precordillera (PC) and western Sierras Pampeanas (WSP), and the Chilenia terrane to the west, forming the basement of the principal and frontal Cordillera (PFC).

The regional tectonics involves a three-stage evolutional history that included accretion during the Famatinian orogeny (Early Ordovician to Early Cretaceous), extension during the Gondwanic cycle (Early Carboniferous to Early Cretaceous), and compression again, during the Andean orogeny (Early Cretaceous to present) (Ramos, 1988) that reactivated and inverted previous accretionary structures. As a result, a

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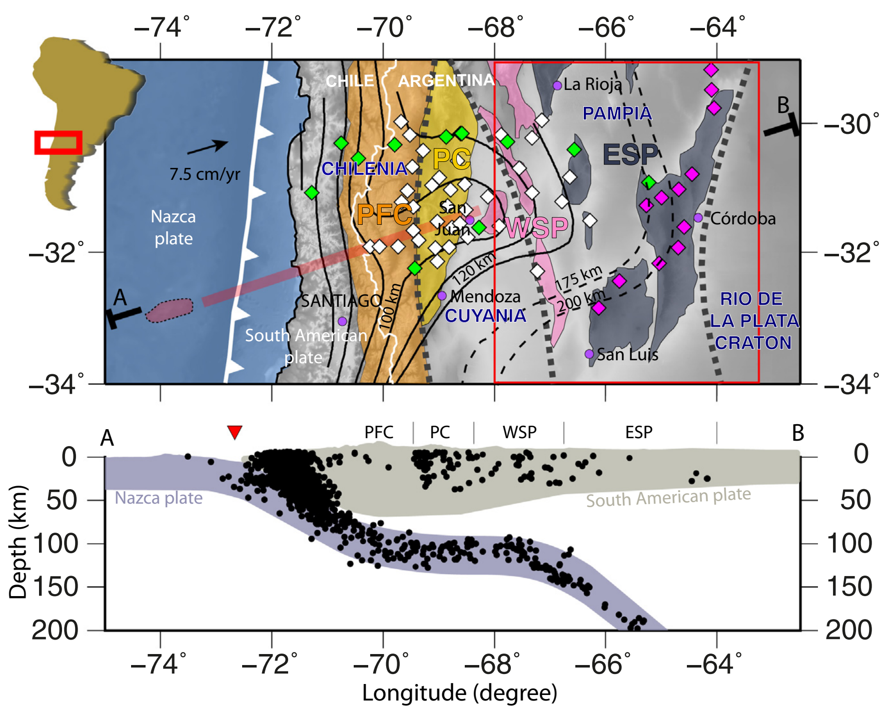

Fig. 1. (top) Location map centered on the flat slab region of the South Central Andes. Thick dashed lines mark terrane boundaries (Ramos et al., 2002; Rapela et al., 2011). Slab top contours are shown by thin black lines (Anderson et al., 2007) and thin black dashed lines (Mulcahy et al., 2014). Locations of the different seismic stations deployed in the region are marked by the green (CHARGE), white (SIEMBRA) and pink (ESP) diamonds. The red thick line shows the path of the JFR subducting under the South American plate (Yáñez et al., 2002). The convergence orientation and rate between the Nazca plate and the South American plate is from DeMets et al. (2010). The red rectangle delimitates our study region. Main cities and localities from both countries are shown by magenta circles. (bottom) Cross-section A-B showing intra slab and intra crustal seismic locations (Marot et al., 2013). PFC: Principal and Frontal Cordillera; PC: Precordillera; WSP: western Sierras Pampeanas; ESP: eastern Sierras Pampeanas (Ramos, 1988). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

series of thin-skinned and basement-cored uplifts extends up to 700 km east from the Nazca-South America trench in the Precordillera and the Sierras Pampeanas. Those three main accreted units exhibit seismic activity mostly along their suture zones (Brooks et al., 2003; Alvarado et al., 2007; Ammirati et al., 2015, 2016). Among those structures, a NW-SE oriented suture zone bounding the western flank of the Valle Fértil–La Huerta range (VFLH) (western Sierras Pampeanas) extends about 600 km, marking the transition at the surface between the terranes Cuyania (west) and Pampia (east) (Snyder et al., 1990; Ramos et al., 2002; Otamendi et al., 2009). Recent termochronological, neotectonic and geophysical studies indicate that this structure seems to play a major role in the uplift of the western Sierras Pampeanas (Ortiz et al., 2015).

The eastern Sierras Pampeanas (ESP) between 29°S to 34°S and 64°W to 67°W (Figs. 1 & 2a) represent the easternmost manifestation of crustal shortening for which the deformation mainly consists of tilted basement blocks bounded to the west by high dipping reverse faults (Ramos et al., 2010). The resulting ranges thus present an asymmetric shape, stretched along the N-S direction with a steep western flank and a low-angle slope on their eastern side. Although the deformation of the eastern Sierras Pampeanas mainly affects rocks of Neoproteozoic to early Paleozoic ages (Fig. 2a), geologic evidence shows that the uplifting began much more recently, during the Miocene, by the tectonic inversion of Cretaceous faults (Siegesmund et al., 2010; Martino et al., 2016). The uplift of the eastern Sierras Pampeanas appears to be synchronized with the flattening of the Nazca plate, as evidenced by the eastward migration of arc volcanism during the past 15 Ma (Kay and Abbruzzi, 1996). Seismological and resistivity studies (Cahill and Isacks, 1992; Booker et al., 2004; Mulcahy et al., 2014) detected what appears to be the top of the slab lying around 175 km depth beneath the Sierras de Córdoba in the ESP (Figs. 1 & 2a). Observations and dating of volcanic rocks show volcanic activity in the central portion of the ESP ~4.7 Ma in the Sierra de Pocho at ~31°S (Gordillo and Linares, 1981; Kay and Gordillo, 1994) and ~1.9 Ma in the southern ESP, in the Sierra de San Luis (El Morro) at ~33°S (Urbina et al., 1997) (Fig. 2a).

Recent seismicity records and historical earthquakes (INPRES, 2018) show that this region is currently active within both upper and lower plate levels (Fig. 1). The general objective of this study is to determine an improved lithospheric velocity structure in the eastern Sierras Pampeanas involving crustal details, to better understand the regional tectonics, their connection with the western Sierras Pampeanas and the flat subduction of the Nazca plate. In the future, our improved velocity structure could be used to improve the seismic characterization of shallow events in this region.

2. Previous geophysical studies

This study uses data from three seismic experiments deployed between 2000 and 2010 (Fig. 1); The **CH**ile **AR**gentina **G**eophysical **E**xperiment (CHARGE) from November 2000 to August 2002; The **SI**erras Pampeanas **E**xperiment using a **M**ulticomponent **BR**oadband **A**rray (SIEMBRA) from December 2007 to December 2009 and the **E**astern **S**ierras **P**ampeanas experiment (ESP) from September 2008 to August 2010. Those experiments were deployed in the Pampean flat slab region to investigate relationships between the subducting Nazca Plate and the crustal shortening observed at the surface (Figs. 1 & 2).

Using P- and S-wave traveltime tomography, Wagner et al. (2005) constrained the wave velocity within the subducting Nazca plate and the overlying mantle. Their findings, later confirmed by Porter et al. (2012) using a combination of earthquake generated surface wave and Ambient Noise Tomography (ANT), evidenced that the subducting plate geometry seems to control the water content and temperature of the overlying mantle wedge. In particular, the region exhibits a hydrated slab and a dry overlying mantle wedge within the flat portion of the slab (beneath the Precordillera) and a dry slab with a hydrated overlying mantle wedge beneath the ESP (Wagner et al., 2005; Alvarado et al., 2007; Porter et al., 2012).

Receiver function (RF) observations from the Pampean flat slab region found the crust to be 50 km thick beneath the western Sierras Pampeanas, > 60 km beneath the Precordillera and ~70 km thick beneath the Frontal and Principal Cordillera (Gilbert et al., 2006; Calkins et al., 2006; Perarnau et al., 2010; Gans et al., 2011; Ammirati et al., 2013, 2015). In addition to these RF results, other studies that used a range of seismic methods observed similar crustal thicknesses (Regnier et al., 1992; Alvarado et al., 2007; McGlashan et al., 2008).

The seismic velocity structure combined with petrological analyses (Pérez Luján et al., 2015) provided evidence that the composition of the Cuyania basement consists of dense mafic to ultramafic rocks, which