Tectonophysics 682 (2016) 120–133

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Central Andean crustal structure from receiver function analysis

Jamie Ryan [a,*], Susan Beck [a], George Zandt [a], Lara Wagner [b], Estela Minaya [c], Hernando Tavera [d]

[a] University of Arizona, Department of Geosciences, 1040 4th St., Tucson, AZ 85721, USA
[b] Carnegie Institution for Science, Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, 20015-1305 Washington, DC, USA
[c] Observatorio San Calixto, Calle Indaburo 944, Casilla, 12656 La Paz, Bolivia
[d] Instituto Geofísico del Perú, Calle Badajoz #169, Mayorazgo IV Etapa, Ate Vitarte, Lima, Peru

ARTICLE INFO

Article history:
Received 12 November 2015
Received in revised form 10 April 2016
Accepted 28 April 2016
Available online 8 May 2016

Keywords:
Crustal thickness
Central Andes
Receiver functions
Isostasy

ABSTRACT

The Central Andean Plateau (15°–27°S) is a high plateau in excess of 3 km elevation, associated with thickened crust along the western edge of the South America plate, in the convergent margin between the subducting Nazca plate and the Brazilian craton. We have calculated receiver functions using seismic data from a recent portable deployment of broadband seismometers in the Bolivian orocline (12°–21°S) region and combined them with waveforms from 38 other stations in the region to investigate crustal thickness and crust and mantle structures. Results from the receiver functions provide a more detailed map of crustal thickness than previously existed, and highlight mid-crustal features that match well with prior studies. The active volcanic arc and Altiplano have thick crust with Moho depths increasing from the central Altiplano (65 km) to the northern Altiplano (75 km). The Eastern Cordillera shows large along strike variations in crustal thickness. Along a densely sampled SW–NE profile through the Bolivian orocline there is a small region of thin crust beneath the high peaks of the Cordillera Real where the average elevations are near 4 km, and the Moho depth varies from 55 to 60 km, implying the crust is undercompensated by ~5 km. In comparison, a broader region of high elevations in the Eastern Cordillera to the southeast near ~20°S has a deeper Moho at ~65–70 km and appears close to isostatic equilibrium at the Moho. Assuming the modern-day pattern of high precipitation on the flanks of the Andean plateau has existed since the late Miocene, we suggest that climate induced exhumation can explain some of the variations in present day crustal structure across the Bolivian orocline. We also suggest that south of the orocline at ~20°S, the thicker and isostatically compensated crust is due to the absence of erosional exhumation and the occurrence of lithospheric delamination.

1. Introduction

The Central Andean Plateau (CAP) is the second highest plateau on Earth and is associated with a convergent margin where the oceanic Nazca plate subducts beneath the continental South American plate. The central Andes are an ideal place to study convergent margin processes and the structure of overthickened continental crust. The CAP, defined as the region over 3 km in elevation, consists of three distinct provinces from west to east; the active volcanic arc of the Western Cordillera, the internally drained Altiplano and the inactive fold and thrust belt of the Eastern Cordillera (McQuarrie and DeCelles, 2001). Further east is the active fold and thrust belt of the Subandean zone, and the modern foreland of the Beni basin. Previous studies have shown that the CAP is characterized by thick continental crust and greater than 275 km of crustal shortening in the back-arc region (McQuarrie et al., 2005; 2008; Oncken et al., 2006; Eichelberger et al., 2015 and other references therein).

In 2010 an array of 50 broadband seismometers was deployed for 2 years in northwest Bolivia and southern Peru as part of the Central Andean Uplift and Geodynamics of High Topography (CAUGHT) project funded by the NSF-Continental Dynamics program. In this study we use data recorded by the CAUGHT seismic array, combined with additional data from permanent seismic stations and previous portable broadband deployments, to determine the crustal thickness and structure of the crust in the Bolivian orocline section of the central Andes in northern Bolivia and southern Peru. Our goal in this paper is to provide more detailed images of the crustal structure of the northern and central Andean Plateau that can be used as constraints to gain insights into possible mechanisms of plateau formation and uplift. We also identify two sections of undercompensated crust in the Eastern Cordillera that may be a result of their proximity to regions of higher precipitation.

2. Tectonic setting

The CAP region of northwestern Bolivia and Southern Peru extends roughly 400 km from the volcanic arc to the Subandean zone. The

* Corresponding author.
E-mail addresses: jgeoryan@email.arizona.edu (J. Ryan), slbeck@email.arizona.edu (S. Beck), gzandt@email.arizona.edu (G. Zandt), lwagner@carnegiescience.edu (L. Wagner), eminaya@observatoriosancalixto.com (E. Minaya), hernando.tavera@igp.gob.pe (H. Tavera).

http://dx.doi.org/10.1016/j.tecto.2016.04.048
0040-1951/

Altiplano is an internally drained basin, with average elevations of ~3.8–4 km, between the high peaks of the Western and Eastern Cordilleras that reach up to 6 km. Volcanoes define the present-day extent of the magmatic arc in the Western Cordillera (Fig. 1). The Eastern Cordillera along this section of the Andes is an inactive fold and thrust belt that contains Triassic and Miocene plutons (Isacks, 1988; Kley, 1999; McQuarrie and DeCelles, 2001; Gillis et al., 2006). The Interandean zone, located between the Eastern Cordillera and Subandean zone, is a region that was uplifted by imbricated basement material between 10 and 5 Ma, as shortening propagated east into the active, thin-skinned fold and thrust belt in the Subandean zone (Kley, 1996; McQuarrie et al., 2005).

Of interest in this study is the northern portion of the CAP, from roughly 12°–20°S to 63°–72°W. This region lies in one of the widest sections of the CAP at the Arica Bend, and has undergone significant upper crustal shortening in the backarc. Numerous studies have found higher amounts of shortening, up to 350 km, in the orocline region than in either the Puna region to the south, where backarc shortening is closer to ~200 km, or in the Andean region farther north in Peru where shortening is ~175 km (Kay and Kay, 1993; Allmendinger and Gubbels, 1996; Kley and Monaldi, 1998; McQuarrie et al., 2008; DeCelles et al., 2011; Gotberg et al., 2010). McQuarrie et al., (2008) partitions the overall upper crustal shortening between 14 and 18°S into the tectonic provinces along the orocline axis in roughly the following amounts: 39 km in the Altiplano, 171 km in the Eastern Cordillera and Interandean zones, and 66 km in the Subandean zone. Upper crustal shortening has occurred in the region, at an essentially constant rate, from roughly 45–0 Ma (McQuarrie et al., 2008; Eichelberger and McQuarrie, 2015). While exhumation rates are fairly consistent with proposed shortening models from 45 to 0 Ma, there is proposed surface uplift of ~1.5–3 km since 10 Ma with little associated upper-crustal shortening in the Eastern Cordillera and continued exhumation of the Eastern Cordillera from 15 to 0 Ma (Gillis et al., 2006; Garzione et al., 2006; McQuarrie et al., 2008; Leier et al., 2013).

Recent climate studies have instead suggested that uplift of the region in the 15–0 Ma time frame was less than 1 km (Poulsen et al., 2010; Insel et al., 2012).

These differences in the timing of upper-crustal shortening and exhumation, as well as ~12 Ma low relief surfaces identified throughout the Eastern Cordillera, have been used to argue that two separate phases

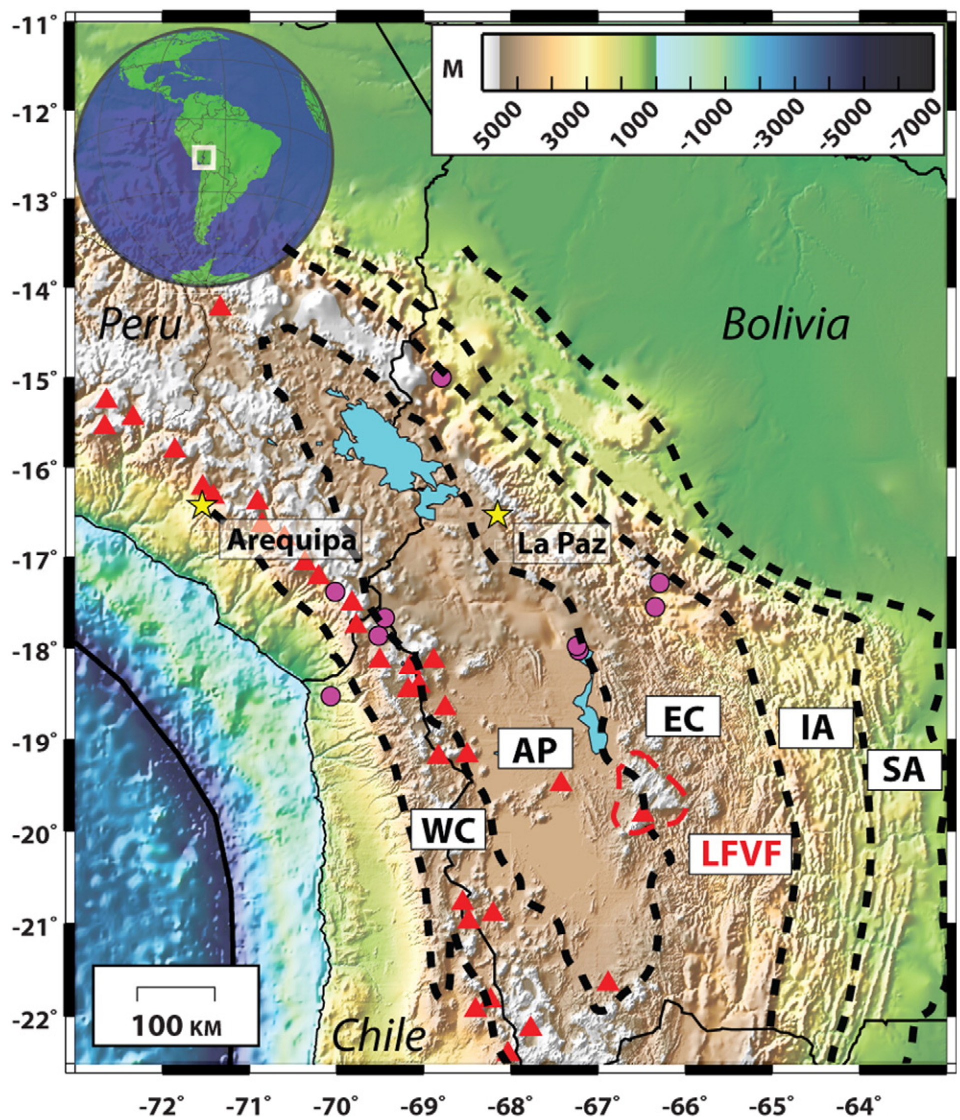

Fig. 1. Topographic map of the central Andes and geomorphic province boundaries for the Western Cordillera (WC), Altiplano (AP), Eastern Cordillera (EC), Interandean (IA), and Subandean Zone (SA).
Modified from McQuarrie et al. (2008) and Mosolf et al. (2010); Holocene volcanoes shown as red triangles. The Los Frailes Volcanic Field (LFVF) is outlined in dashed red. Yellow stars show the location of major population centers, and purple circles show the location of local events used in the Wadati diagram (Fig. 4).