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Change in the pattern of crustal seismicity at the Southern Central Andes from a local seismic network

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ABSTRACT

Shallow seismicity in the Southern Central Andes is associated with interplate earthquakes due to the subduction of the Nazca plate beneath the South American plate and neotectonic activity, mainly located in the retro-arc region. However, this pattern changes drastically south of 34°S within the transition zone at the Southern Central Andes where crustal seismicity associated with mountain-building processes concentrates at the fore-arc and intra-arc region. In order to define more accurately this transition we used data from a high density-seismic network over the Chilean fore-arc and axial Andean sector (~33–34.5°S). We obtained a constraint data set of 77 seismic events located mostly in the Principal Cordillera western flank in the first 10 km of the upper crust. This cluster implies an abrupt change in the pattern of seismicity at the Southern Central Andes with a set of structures in the fore-arc and intra-arc accommodating shortening. This change in the locus of crustal seismicity and particularly its location on the fore-arc and intra-arc south of 34°S is discussed on the light of different hypotheses among which changes in the precipitation pattern and erosion along the Andes were favored. Focalized erosion associated with direction of prevailing Pacific winds south of ~34°S could determine subcritical conditions that could be adjusted by out-of-sequence deformation causing crustal earthquakes in the fore-arc region, becoming the retro-arc zone nearly fossilized from a deformational point of view. Additionally, trench sediments associated with this change in the precipitation pattern could also favor decoupling of the subduction zone inhibiting retro-arc seismicity, although it does not explain activation of fore-arc structures south of 34°S and their absence north of this latitude. Finally, inhomogeneous distribution of seismicity through the fore-arc zone south of 34°S is discussed on the light of variable elastic thicknesses.

1. Introduction

Crustal seismicity across the Andes, the longest and highest subduction-related orogen on Earth, denotes active mountain building activity and therefore has been a matter of interest and analysis through time (Isacks et al., 1982). Intraplate shallow seismicity exhibits low magnitudes and its occurrence is less frequent than in giant underthrusting events which occur in the interface between the subducted oceanic lithosphere and the overriding plate. Due to that most of the attention has been paid to this stronger seismicity with rupture areas reaching hundreds of kilometers, widespread strong shaking, and destructive tsunamis, distribution and occurrence of crustal earthquakes are not fully understood along the Andes yet (Christensen and Ruff, 1986; Beck et al., 1998; Moreno et al., 2009; Lange et al., 2012; Ruiz et al., 2013; among others).

Crustal seismicity, its distribution and main patterns allow establishing segmentation related to mountain building processes independently to that of giant earthquakes in the subduction zone. In particular, crustal seismicity between ~33°S and 35.5°S through the Southern Central Andes (Gansser, 1973) experiences a shift in locus between patches of concentrations on the eastern Andean foothills in the north and clusters implanted in the fore-arc and intra-arc region in the south (Fig. 1).

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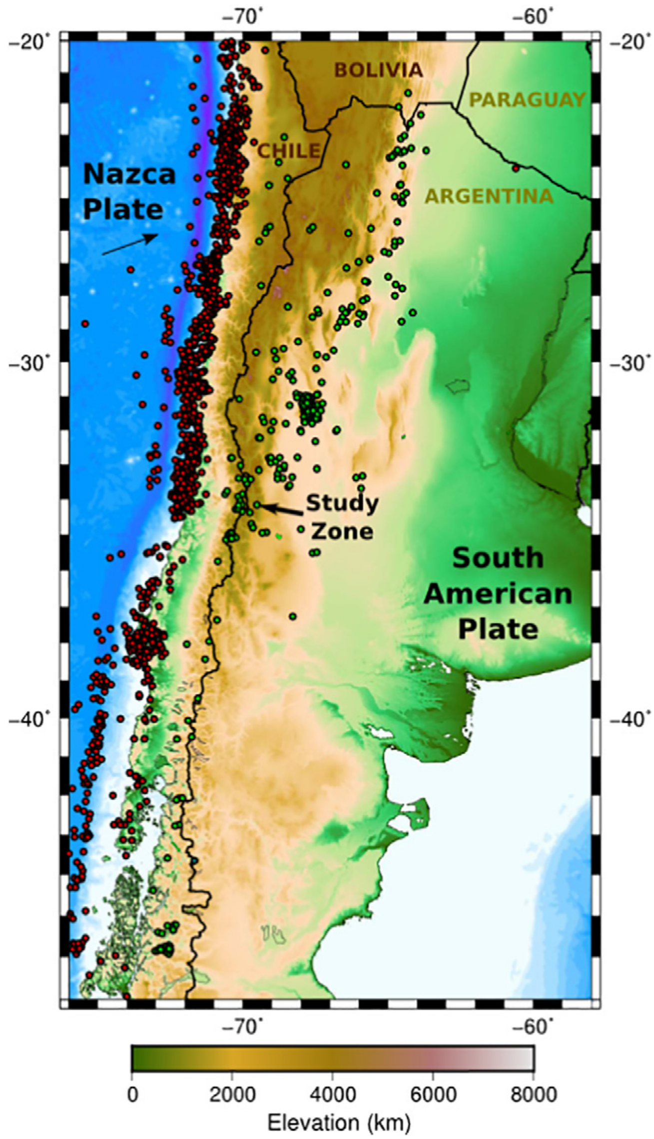

Fig. 1. Seismicity (depth: 0–50 km) corresponding to a period of time of ~48 years (International Seismological Centre, EHB Bulletin, http://www.isc.ac.uk, Internatl. Seis. Cent., Thatcham, United Kingdom, 2009). The EHB is a groomed version of the ISC Bulletin, and contains data for 141,478 events from 1960 to 2008. The Engdahl et al. (1998; EHB) algorithm has been used to significantly improve routine hypocenter determinations made by the ISS, ISC and PDE. The epicenters located between the trench and the coastal zone correspond to the interplate seismicity (red circles) associated with the contact between the Nazca and South American plates. The epicenters located partly in the fore-arc, and basically at the intra-arc and back-arc zones correspond to the intraplate seismicity (red circles) associated with the South American plate and in particular to mountain building processes. Note the strong change in the pattern of seismicity from an active back-arc in the north to an active fore-arc and intra-arc south of ~34°S.

Crustal earthquakes through these latitudes have been registered by global (Fig. 1) and by regional/local networks (Alvarado, 1998; Pardo et al., 2002; Barrientos et al., 2004; Farías, 2007) showing this transition in the pattern of seismicity at around 34°S. Barrientos et al. (2004) studied this seismicity at the transition area, locating it no deeper than 20 km and close to the Chile-Argentina boundary. Thus, this shallow crustal seismicity has become aligned with a structure that conforms The El Fierro Fault (Farías, 2007).

This work provides precise location of these very shallow earthquakes through the transition zone between an active back-arc in the north through the Southern Central Andes and an active fore-arc and intra-arc in the south and focal mechanism solutions from a dense network (Fig. 2). To obtain well-resolvable hypocenter determinations we used a location technique to relocate seismicity that tests the entire solution space by a direct and grid search method (Rodi, 2006). The location parameters of a set of events are determined jointly with travel-time corrections associated with the paths between the recording stations and the seismic events. As mentioned, at the latitudes of the study zone (Fig. 1), crustal earthquakes experiment a drastic change from the retro-arc north of ~34°S to the intra-arc and fore-arc zones south of this latitude. This change coincides with a strong variation in the patterns of rainfall and erosion. While north of these latitudes the fore-arc is essentially dry, south of these latitudes Pacific-derived winds provoke a drastic increment in rain fall.

Analogue and numerical experiments suggest that climate and erosion (e.g. storm runoff), play a crucial role controlling patterns of tectonic deformation and metamorphism across orogens, determining uplift and exhumation rates (e.g. Persson and Sokoutis, 2002; Dadson et al., 2003). This work, allow discussing the potential of climate and erosion in focusing crustal deformation through new data collected from a local network at one of the most striking sites of crustal seismic segmentation along the Southern Central Andes. Thus a connection is proposed between the development of fore-arc and intra-arc seismicity south of 34°S, a noticeable fall of this activity in the retro-arc zone and rainfall and short- and long-term erosion rates established in previous works.

Additionally, a discontinuous pattern in fore-arc and intra-arc crustal seismicity is observed south of 34°S at the Southern Central Andes. This pattern is discussed on the light of variable elastic thicknesses and thermal structure of the fore- and retro-arc zones. Thus, gravity data are used to calculate elastic thicknesses through the continent that are compared with earthquake density through the fore-arc identifying zones where low crustal rigidity could be inhibiting seismic activity.

1.1. Seismotectonic and tectonic settings

Seismicity shows that western South America is characterized by a convergent margin, in which the Nazca, Cocos and Antarctica plates are subducted underneath the South American plate with variable angles that range between ~30° and 0° (Cahill and Isacks, 1992; Pardo et al., 2002; Anderson et al., 2007; Nacif et al., 2015). In particular, the Nazca plate subducts at a rate of 6.7 ± 0.2 cm/yr constrained by GPS measurements along the Chile-Peru oceanic trench (Kendrick et al., 2003). Along the convergent margin between the Nazca and South American plates, changes in the angle of subduction can be either abrupt or transitional such as in the Southern Central Andes (Fig. 1), where the Nazca plate progressively steepens from a flat geometry north of ~33°S to a "normal" (~30°E) geometry south of this latitude (Cahill and Isacks, 1992; Araujo and Suarez, 1994; Pardo et al., 2002; Syracuse and Abers, 2006; Anderson et al., 2007; Nacif et al., 2015), associated with the development of an active volcanic arc (Hildreth and Moorbath, 1988; Kay et al., 2005). This active volcanism comprises the northern part of the Andean Southern Volcanic Zone, absent to the north from ~9–10 My through the Chilean-Pampean flat subduction zone (e.g., Kay et al., 1987). Additionally, the Andean margin through these latitudes is characterized by an along strike curvature known as the Maipo Orocline developed during the Neogene, interpreted as the product of a shortening gradient (Yáñez et al., 2002; Farías et al., 2008). South of these latitudes a complex pattern of mantle upwellings characterizes the retro-arc zone associated with intra-plate volcanism. While part of this dynamics is related to mantle-plume activity feeding the Payenia volcanic plateau developed between 35° and 37°S (Burd et al., 2014), a