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Structural characteristics of an active fold-and-thrust system in the southeastern Atacama Basin, northern Chile

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ABSTRACT

The western South American margin is one of the most active plate boundaries in the world. Using various remote sensing data sets, we mapped the neotectonic characteristics of an area at the southeastern corner of the Atacama Basin, northern Chile, in the Andean forearc. There, one major N-S trending ridge is clearly visible both in the satellite images and in the field. This ridge reaches 250 m above the basin floor in its middle part and is asymmetrical, with a steep eastern slope and a much gentler western slope. The geometry of the ridge indicates that it formed as an asymmetrical anticline. This anticline is likely formed as a shear fault-bend fold, with a major décollement at a depth of about 2.5 km in the Naranja Formation. We suggest that this décollement is a major structure of the Atacama Basin area. From the ages of the ignimbrites and lake deposits that were deformed by this anticline, we obtained a long-term shortening rate of the major underlying structure at about 0.2 mm/yr. This thin-skinned fold-and-thrust system appears to be active since at least about 3 Ma, and could be as long as since middle Miocene. Therefore, crustal structures may play important roles in the Neogene development of the western Andean margin.

1. Introduction

The continental margin of the western South America is one of the most active plate boundaries in the world. The ongoing convergence between the Nazca and the South American plates produced the wide deformation belt of the Andes, one of the world's longest mountain ranges, during the last 30 Ma (e.g., Isacks, 1988; Allmendinger et al., 1997). The central segment of the orogen, between about 15°S and 28°S, also includes the Altiplano-Puna, one of the largest and highest plateaus in the world, with its average elevation above 3.5 km (e.g., Allmendinger et al., 1997; Gregory-Wodzicki, 2000; Coutand et al., 2001; Tassara, 2005; Fig. 1).

Although the convergence rate between the subducting plates and the South America is as fast as 68–80 mm/yr (e.g., DeMets et al., 1990; Norabuena et al., 1998; Somoza, 1998; Angermann et al., 1999; Gripp and Gordon, 2002), the strain and strain rate distribution across the entire plate boundary belt and the degree of coupling between the plates are not well understood. Whereas most studies have inferred that the plate interface is strongly coupled (e.g., Lamb et al., 1997; Chlieh et al., 2011; Métois et al., 2012), some numerical simulations show that locally the coupling may be only 40–50% (Norabuena et al., 1998; Liu et al., 2000). Therefore, upper plate structures may play a significant role in the accommodation of the plate convergence and the long-term development of the orogen. In the backarc region, slip on structures in the sub-Andean belt is taking up 8–13 mm/yr of shortening (Baby et al., 1997; Kley and Monaldi, 1998; Kley, 1999; McQuarrie, 2002; Echavarría et al., 2003; Brooks et al., 2011). The long-term slip rates of structures in the forearc region, however, is known only locally (e.g., Victor et al., 2004; Farías et al., 2005; Oncken et al., 2006; Allmendinger and González, 2010; Cortés et al., 2012). Detailed information of neotectonic activities in different parts of the forearc region would therefore have important implications for understanding the balance between interplate processes and upper plate deformations in the western side of the Andean orogen.

Furthermore, neotectonic characteristics in the central western Andes may provide important information about the formation mechanisms of the Andean Plateau. While many suggest that a crustal-scale monoclinal fold and tilting produced the western mountain front of the central Andean Plateau (e.g., Isacks, 1988; Hoke et al., 2007; Jordan et al., 2010), some argued that west-vergent upper crustal faults are responsible for the formation of this mountain front (e.g., Muñoz and Charrier, 1996; Victor et al., 2004; Farías et al., 2005; Armijo et al.,

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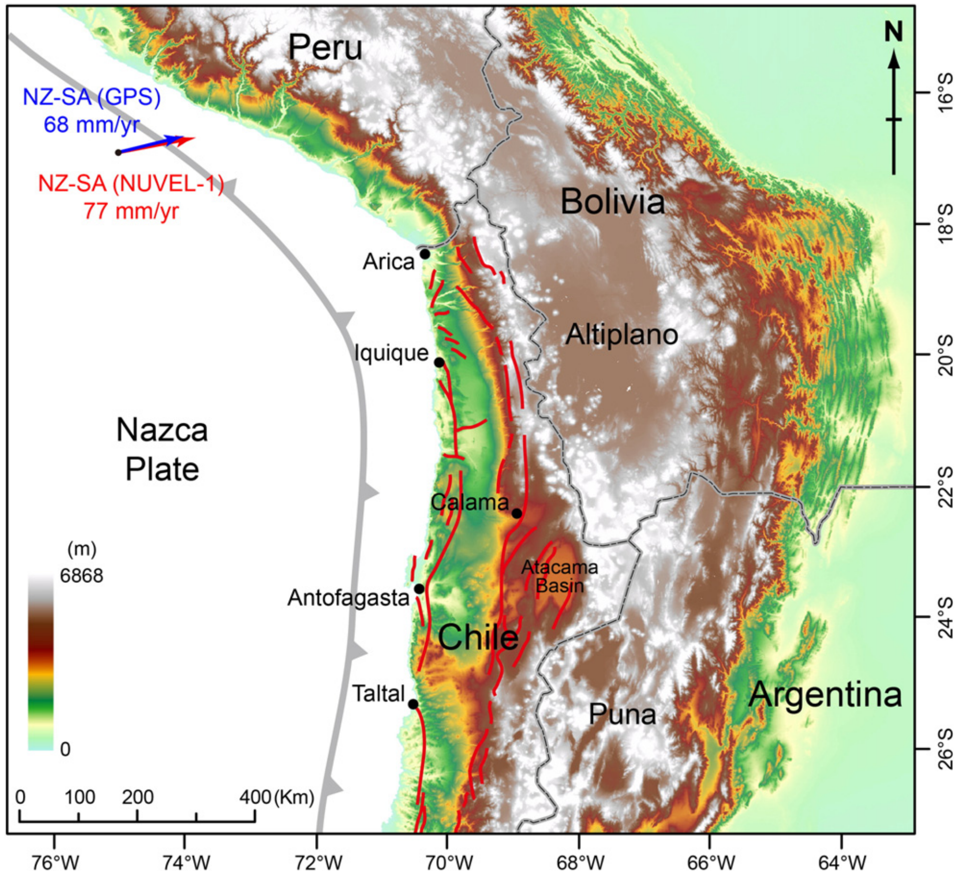

Fig. 1. A shaded relief map that shows the topography and the tectonic framework of the central Andes. Red lines are major geologic structures that have been mapped in previous studies (e.g., Delouis et al., 1998; González et al., 2003, 2006; Riquelme et al., 2003; Allmendinger et al., 2005). The plate convergence vectors between the Nazca (NZ) and the South American (SA) plates are from the NUVEL-1 model (red arrow; DeMets et al., 1990) and from GPS data (blue arrow; Norabuena et al., 1998).

2010, 2015). Since the proposed upper crustal faults are reported only locally, their importance in the formation of the western Andean mountain front is difficult to determine. Therefore, it is important to understand whether such structures are present along other parts of the western Andean forearc, and the characteristics (geometry, slip rate, and timing and amount of deformation) of such structures if they do exist.

In this study, we analyzed the neotectonic characteristics of an area in the southeastern Atacama Basin, northern Chile. Active structures have been reported in this area (e.g., Kuhn, 2002; Jordan et al., 2007), and the tectonic geomorphic features have been described (González et al., 2009). However, the geometrical characteristics of the active structures that may have produced these features and the long-term slip rates of the structures have not yet been systematically analyzed. Thus we performed detailed topographic mapping and measurements, together with precise Ar-Ar and U-Th geochronology of deformed strata in this area, in order to constrain the amounts and rates of the deformation. These data enabled us to obtain the geometry and structural history of the structural systems between 23.5°S and 24°S, and to understand the long-term activity of these structures.

2. Geologic background

Along the central portion of the South American plate boundary, the Nazca plate moves toward the South American plate in the direction of about N78°E, with a rate of about 68–80 mm/yr (DeMets et al., 1990; Norabuena et al., 1998; Somoza, 1998; Gripp and Gordon, 2002). This plate convergence produced the uplift of the central Andes since at least late Oligocene (e.g., Isacks, 1988; Allmendinger et al., 1997; Coutand et al., 2001; Elger et al., 2005). Crustal shortening and thickening may have started from beneath the Altiplano and extended to the east, and magmatism spread across the Altiplano contemporaneously (e.g., Allmendinger et al., 1997).

The western central Andes are characterized by several N-S trending tectonic domains. From west to east, these units are the Coastal Cordillera, the Central Depression, the Precordillera, and the Western Cordillera that forms the crest of the range (e.g., Delouis et al., 1998; Fig. 2). The Coastal Cordillera consists mainly of Mesozoic magmatic rocks and is the remnant of an ancient arc, and the Central Depression is filled with Cenozoic volcanic sedimentary deposits (Scheuber and Reutter, 1992; Hartley et al., 2000). Between about 22°S and 27°S, a Preandean Depression appears between the Precordillera and the Western Cordillera (Soto et al., 2005). This part of the Precordillera also includes the Cordillera de Domeyko. East of the Western Cordillera are the high plateaus of Altiplano and Puna.

The Atacama Basin, also known as the Salar de Atacama Basin, is located at about 23°S and 68°W (Fig. 3). At 150 km long and 80 km wide, it is the largest basin within the Preandean Depression. The flat bottom of the basin is at an elevation of ~2300 m, and the deposits at the basin center is composed of pure halite, surrounded by siliciclastic, carbonate, sulfate sediments and ignimbrites (Jordan et al., 2002). Total thickness of the deposits in the basin is over 6 km (e.g., Schurr and Rietbrock, 2004), and the deposition began in the early Miocene (Flint et al., 1993).

Around the Atacama Basin, several topographic features that may represent recent structural activity have been reported. For example, the Cordillera de la Sal in the western part of the basin is a complex fold-and-thrust belt, and Oligocene to Pleistocene strata there were deformed and uplifted for up to 200 m above the basin floor (Jolley