



Miocene–Quaternary structural evolution of the Uyuni–Atacama region, Andes of Chile and Bolivia

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ABSTRACT

We describe the Miocene–Quaternary geological–structural evolution of the region between the Salar de Uyuni and de Atacama, Andes of Chile and Bolivia. We recognized four main tectonic events based on fold geometry, fault kinematics and stratigraphic data. The oldest event, of Miocene age, is characterized by folding and reverse faulting of the sedimentary successions with an E–W direction of shortening in the northern part of the studied area and a WNW–ESE shortening in the southern part. The following two events, of Pliocene age, are characterized by lower shortening amounts; they occurred first by reverse faulting with a NW–SE-trending greatest principal stress (σ_1 , computed with striated fault planes) and a vertical least principal stress (σ_3), followed by pervasive strike-slip faulting with the same NW–SE-trending σ_1 and a horizontal NE–SW σ_3 . The fourth event, dating to the late Pliocene–Quaternary is characterized by normal faulting: the σ_3 still trends NE–SW, whereas the intermediate principal stress σ_2 exchanged with σ_1 . Volcanism accompanied both the contractional, transcurrent and extensional tectonic phases. The Mio–Pliocene compression appears directly linked to a rapid convergence and an apparently important coupling between the continental and oceanic plates. The E–W to WNW–ESE direction of shortening of the Miocene structures and the NW–SE σ_1 of the Pliocene structures seem to be more linked to an intra-Andean re-orientation of structures following the WNW-directed absolute motion of the South-American Plate. The extensional deformations can be interpreted as related to gravity forces affecting the highest parts of the volcanic belt in a sort of asymmetrical (SW-ward) collapse of the belt.

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1. Introduction

In northern Chile and southwestern Bolivia the Andean chain shows a major general change in the trend of tectonic and volcanic structures; north of 19°S, faults, folds and volcano alignments strike NW–SE, whereas south of 23°S they mainly strike N–S (Fig. 1). The region between 19 and 23°S is structurally characterized by a network of NW- and N–S-striking lineaments. The NW-striking lineaments have been interpreted as left-lateral strike-slip faults based on the apparent offset and curvature of Tertiary main fold systems and on paleomagnetic data (Riller et al., 2001; Matteini et al., 2002; Riller and Oncken, 2003). This region is also affected by a series of N–S reverse faults and NE–SW-striking right-lateral strike-slip major faults (Riller and Oncken, 2003), whereas in northern Chile Kuhn and Reuther (1999) observed NNE-trending folds offset by NNE-striking reverse faults and minor ENE-striking right-lateral and NW-striking left-lateral strike-slip faults.

De Silva et al. (1994) suggest that the NW–SE fractures exerted a possible tectonic control on the distribution of volcanic centres, which are here oblique to the general pattern of volcanism in this part of the Andes. This region is thus significant for understanding the structure of the central Andean chain, as well as the relationship between tectonics and volcanism, which is important: i) as concerns large active volcanoes with strong explosive activity such as, for example, Putana, San Pedro, Ollague and Tata Sabaya; ii) for mineral and geothermal resources, which are closely linked with tectonics and volcanism.

In spite of the relevance of these topics, the studied area lacks of a robust description and interpretation of structural data based on field mapping of brittle and ductile deformation related to sedimentary and volcanic deposits. Clear field evidence of fault kinematics, separation of tectonic phases, and directions of strain and stress are not described in the literature, apart from one structure that reaches the southernmost part of the studied area. This structure is represented by the Olacapato–El Toro Fault Zone, which has been extensively studied in NW Argentina (Petrinovic et al., 2005; 2006; Ramelow et al., 2006). Other data refer to the SE part of the Salar de Uyuni (Elger et al., 2005).

The present paper contributes to the abovementioned topics by presenting a new geological–structural map of a 48,000 km² area (Fig. 2)

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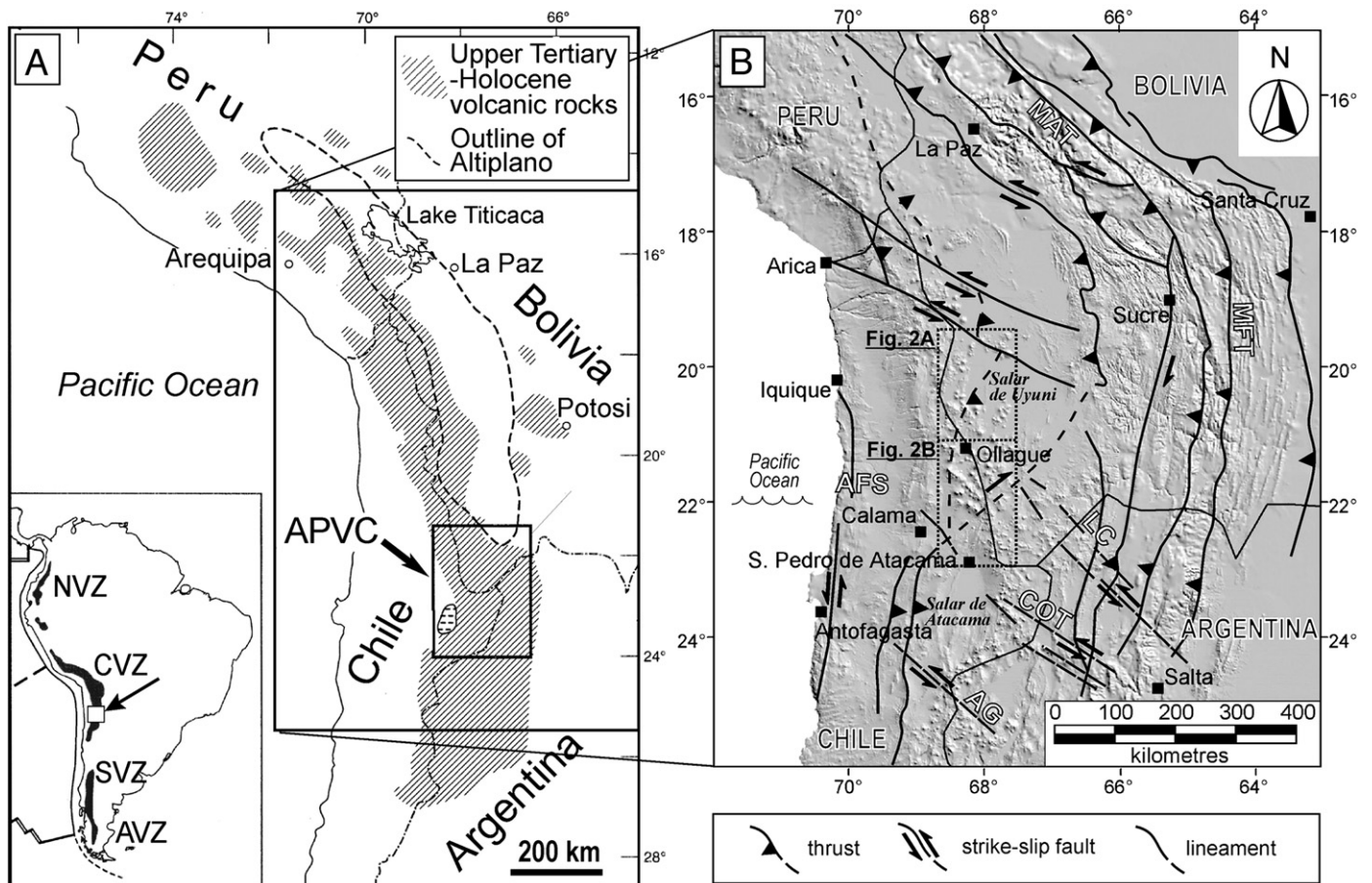


Fig. 1. (A) Physiographic sketch of the Andean Central Volcanic Zone (CVZ) and location of the studied area. APVC: Altiplano–Puna Volcanic Complex. Inset map shows the location of the CVZ and the other active volcanic segments of the Andes: Northern Volcanic Zone (NVZ), Southern Volcanic Zone (SVZ), and Austral Volcanic Zone (AVZ) (modified from de Silva, 1989). (B) Three structurally and geologically different regions (after Herail et al., 1996) characterize the studied area of the Andes: to the east the frontal front of embricated thrust slices of the Bolivian Altiplano, in the middle the chain of volcanoes, located along the border between Chile and Bolivia, and to the west the coastal mountain region of northern Chile characterized by transcurrent activity. Dotted boxes locate the study area and Fig. 2A and B. MAT: Main Andean thrust; MFT: Main Frontal thrust (Herail et al., 1996); LC: Lipez–Coranzuli fault system; COT: Calama–Olacapato–El Toro fault system; AG: Archibarca–Galan fault system (Riller et al., 2001); AFS: Atacama Fault System (Riquelme et al., 2003).

between 19°S and 23°S based on field data integrated with remotely sensed data, which is the starting point for the interpretation of the tectonic evolution and of the links with the distribution and geometry of volcanic centres. The relative age of the volcanoes has been determined comparing lava texture, morphology and degree of erosion of volcano slopes with respect to the radiometrically-dated cones.

2. Regional geological background and tectonic settings

Three structurally and geologically different regions characterize the area of the Andes between 19°S and 23°S: i) to the east—in central Bolivia—the front of imbricated thrust slices, ii) in the middle—along the Chile–Bolivia border—the chain of volcanoes, whose structural setting is poorly understood, and iii) to the west, the coastal mountain region of northern Chile, characterized by transcurrent Quaternary activity (Fig. 1B). To the north and to the south the area is bordered, respectively, by the large Uyuni and Atacama Salares.

The eastern region of imbricated thrust slices is mainly constituted by a Paleozoic to Miocene sequence of metamorphic and sedimentary rocks (Marsh et al., 1992). Structural studies indicate a sequence of foreland dipping duplexes with thrust faulting following an about E–W direction of shortening (Herail et al., 1996; Kley, 1999). Folds are characterized by dominant N–S-trending hinge lines. The central volcanic belt is characterized by eruptive centres mainly aligned along a NW–SE corridor, oblique to the main N–S orientation of this part of

the Andean Volcanic Arc (de Silva et al., 1994). The western coastal region is made of Paleozoic metasedimentary rocks and Mesozoic plutons and volcanic rocks (Scheuber et al., 1994; Riquelme et al., 2003). Here, the dominant tectonics is given by N–S-striking faults, some of which are active. The most important structure is the left-lateral strike-slip Atacama fault system (Scheuber et al., 1995; Taylor et al., 1998; Riquelme et al., 2003).

The geological map in Fig. 2 results from the integration of new stratigraphic data with the available literature (Ramírez and Huete, 1980; Marsh et al., 1992; SGM, 1997a,b). The oldest deposits are represented by marine sedimentary rocks of Jurassic–Late Cretaceous age that crop out in the southernmost part of the area. Sedimentary rocks of Early Miocene age crop out in the central–northern part, southwest of the Salar de Uyuni. These deposits are covered by a series of Early Miocene lava flows and Late Miocene lava flows and ignimbrites. In particular, several largely-dissected stratovolcanoes of Late Miocene age have been recognized, most of them showing a clear NW–SE alignment. Pliocene–Quaternary volcanic deposits, resulting from a dominantly effusive activity, are ascribed to different stratovolcanoes, and also include ignimbrite plateaux. Pliocene and Pleistocene ignimbrites have been erupted in two main phases of caldera collapse, the largest structure being the Pastos Grandes caldera (Fig. 2B; SGM, 1997a). In the study area of Fig. 2, effusive activity also concentrated in correspondence with central stratovolcanoes which have been here distinguished into Pliocene and Late Pliocene–Pleistocene age edifices. Pliocene volcanoes are distributed

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