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We propose two deformational events. The first, an early contractional event whose contraction directions varies from E-W to NE-SW near to Permian basement blocks, whose structural architecture is controlling the NW-SE and E-NE strike slips faults generated on the second event and the orientation of folds and faults developed during the first one. A Strike-Slip deformation is observed by faults that cut Miocene-Pliocene volcanic units and the previous contractional system. Because the reverses faults and folds are affecting the Oligocene Miocene rocks, the early contractional event documented in our kinematic analysis was active at least until the lower to mid Miocene times. The late deformational event is represented by the strike slip deformation that was active until recent times, defining in this way the temporality of deformation in Frontal Cordillera, in the transition with the Puna Plateau.

1.III The Inner Forearc of the Central Andes (21°-23°S): Structural Styles, Age of Uplift and its Relation with Basement Weakness Zones

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Introduction and geological background

The inner forearc of the Central Andes in northern Chile consist of a series of intermontane basins defined as Pre-Andean basins and salars bounded by the Chilean Precordillera (or Domeyko Cordillera) and the current volcanic arc (Figure 1). They correspond to: the Salar de Atacama, the Punta Negra and the Salar de Pedernales basins (Figure 1). Considering that these are covered regions, the main interpretations of their internal structure and stratigraphy have been constructed from the study of the neighboring areas, such as the Domeyko Cordillera (Figure 1). The excellent expositions of structural and stratigraphic relationships in these areas have allowed propose idealized and hypothetical models for the tectonic setting of the basins, however; only some few recent works have taken advantage of 2D seismic profiles and borehole data to constrain the subsurface Andean structures in the region.

Based on the above, several models are invoked to explain the structure of the inner forearc of the Central Andes in northern Chile, which include: a) Late Cretaceous to Recent contraction developing east-verging thrust systems (Muñoz et al., 2002; Arriagada et al., 2006), b) multipisodic Cenozoic extensional and contractional deformation (Pananont et al., 2004, among others), c) Late Cretaceous basin inversion accompanied of basement reverse faulting (Bascuñan et al., 2019; Martínez et al., 2018; 2020), among others. The latter, accounts for the great uncertainty that still exists regarding this issue. In order to solve this problem, we have developed an integrated study supported by the geological interpretation of more than 38.000 km of 2D seismic profiles, field observations, borehole and geochronological data. Two basins were studied: the Salar de Atacama and the Salar de Punta Negra basins, respectively (Figure 2), and, for first time we presented two regional-scale transects showing the distribution of the main structural styles along the inner forearc of the Central Andes in northern Chile.

In both basins, the oldest geological units consist of Paleozoic granitic and volcanic rocks exposed along kilometeric-scale blocks in the eastern Domeyko Cordillera and also at isolated outcrops in the western volcanic arc (Figure 1). They are followed by Permian to Mesozoic (Triassic-Jurassic) volcanic and sedimentary megasequences reaching stratigraphic thickness of near of 3 km. These form large stratigraphic wedges controlled by ancient east and west-dipping basement normal

faults related to the creation of rift systems and back-arc extensional half-graben structures, and therefore, these are interpreted as syn-rift deposits (Figure 2). The top of the Mesozoic syn-rift is unconformably covered by Upper Cretaceous to Cenozoic volcanic and siliciclastic synorogenic deposits (Figure 2), which mostly cover anticline and syncline folds. Within the Cenozoic record several angular unconformities are recognized, thus recording different tectonic pulses.

Data and methods

The seismic data used correspond to several regional-scale grids distributed along the Salar de Atacama, Salar de Punta Negra. The grids are composed of N-S and E-W-oriented 2D seismic profiles acquired using both vibroseis and explosives. The profiles typically exhibit good to moderate quality with very good seismic reflection patterns within the first two seconds. In order to improve the quality of the seismic data, we increased the seismic amplitude contrast of those seismic reflectors related to angular unconformities and fault planes using the Move software of Midland Valley Company. After this process, we examined the position and geometry of the faults and folds, as well as the stratigraphic boundaries of the main tectonosequences. We constructed two large geological cross-sections from the Domeyko Cordillera to the volcanic arc (Figure 1).

The sections were oriented perpendicular to the strike of the first-order structures (Figure 1) to show the real inclinations of the structures as much as possible. The cross-sections were located in the widest parts of the Pre-Andean basins in order to cover the greatest length. To their construction we applied the follow workflow: a) construction of topographic profiles along the sections, b) plot of the geological contacts, dip domains and structures observed in surface over the topographic profile, c) the interpretation of the seismic profiles was incorporated in the cross-section drawing by hand the first-order structures and also considering the measured thickness for the stratigraphic successions, d) in order to complete the cross-sections. the structures exposed on surface were projected down and them these were connected with those recognized in the 2D seismic data. We also integrated geochronological data composed of U-Pb ages of volcanic and detrital zircons from bed rocks of synorogenic deposits and apatite fission track ages for granitic units related to pre-rift basement rocks. Both techniques were applied to determine the timing of contractional deformation and exhumation of the first-order structures bounding the inner forearc.

Results and conclusions

The field and seismic data revealed a complex array of basement structures composed of doubly-verging inverted normal and reverse fault and rotated and reworked basin margins (Figure 3). The geometry and kinematics of the basement-involved contractional faults and folds are strongly controlled by the reactivation of previous zones of crustal weakness in the upper crust, which consist of ancient Upper Paleozoic to Mesozoic normal faults (Figure 3). Many of these were positively reactivated and inverted, thus creating asymmetrical inversion anticlines along the central sections of the basins. Upper Cretaceous synorogenic deposits covering the inversion anticlines mark the beginning of the basin inversion. Moderate dipping reverse faults are interpreted to occur after the basin inversion, being they the most effective structures for generating crustal thickening. Commonly, these structures are complex and dominated by doubly-verging faults influenced by the original dip and spacing of ancient normal faults. In areas where ancient high-angle normal faults are separated by narrow structural highs, the basement structures tend to be more complex because some inverted normal faults are rotated and reworked and even superimposed on other faults, which greatly complicates the dip and vergence

of these structures. Apatite fission track ages of granites from the hanging wall fault blocks reported Paleocene to Eocene ages, thus indicating an important and rapid exhumation process. In contrast to other basement-involved structures recognized in foreland settings and classified as low-temperature structures, considering their positions in a hot forearc setting, the structures in the inner forearc of northern Chile can be interpreted as high-temperature structures. The Cenozoic eastward migration of the volcanic arc in northern Chile could also have facilitated the propagation of these basement-involved structures. During this process, there would be a considerable increase of the heat flux in the lithosphere, which would change the initial mechanical and rheological conditions of the upper crust. Additionally, this process may have facilitated the upward propagation of basement structures and can explain the presence of large basement-involved structures in the inner forearc of the Central Andes.

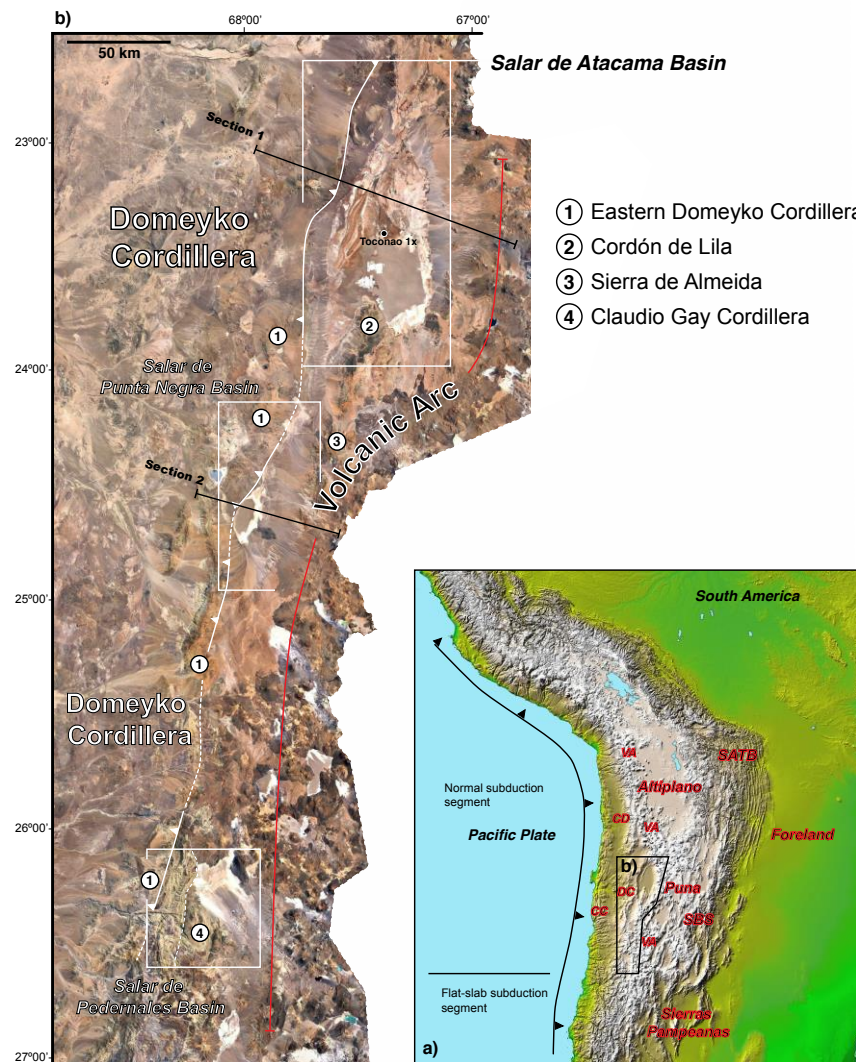


Figure 1. a) The Central Andes of South America and the distribution of major tectonic provinces along the normal subduction segment and forearc and back-arc regions and the location of the regional-scale cross-sections showed in this work. SAB: Sub-Andean Belt, SBS: Santa Barbara System, VA: volcanic arc, DC: Domeyko Cordillera, CD: Central Depression, CC: Coastal Cordillera.

b) Satellite mosaic of the forearc region of northern Chile (23–27°S) showing the location of Pre-Andean basins and the regional cross-section discussed in this work. 1-4: main outcrops of granitic Paleozoic rocks.

Geological Age		Seismic pattern	Seismic tectonosequences	Interpreted geological units	
Cenozoic	Neogene	T6	T6	SAB	SPNB
				Vilama Fm.	Volcano-sedimentary successions
				Paciencia Group	Pampa de Mulas Fm.
	Paleogene	T3	T3	Loma Amarilla Fm.	
				Purilactis Group and Naranja Fm.	
				Sierra de Varas and El Profeta Fms.	
Mesozoic	Cretaceous	T2	T2	Sierra de Varas and El Profeta Fms.	
				Lila Complex	
				La Tabla and Zorritas Fms.	
Upper Paleozoic	Permian	T1	T1	Mainly granitic rocks	
				Mainly granitic rocks	
				Mainly granitic rocks	

Figure 2. Stratigraphic template showing the proposed correlation between the tectonosequences interpreted in this work and the geological units exposed along the Salar de Atacama and Salar de Punta Negra basins. The seismic profile corresponds to the central section located along the central part of the Salar de Atacama Basin. The projection of the Toconao-1 oil well is indicated into the seismic data. Abbreviations: SAB: Salar de Atacama Basin, SPNB: Salar de Punta Negra Basin.

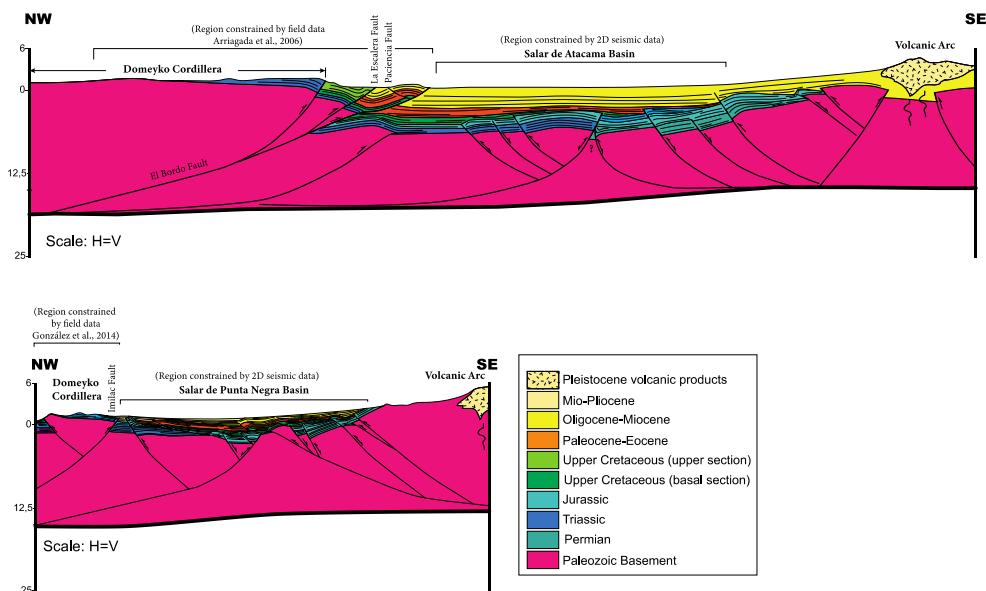


Figure 3. Upper section: regional-scale cross-section (section 1 in figure 1) extended from Domeyko Cordillera to the present-day volcanic arc showing the main basement-involved

structural styles under the Salar de Atacama Basin and their relationship with those interpreted in neighboring regions. Lower section: regional-scale cross-section (section 2 in figure 1) extended from Domeyko Cordillera to the present-day volcanic arc showing the main basement-involved structural styles under the Salar de Punta Negra Basin and their relationship with those interpreted in neighboring regions.

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1.IV Structural Style, Evolution and Along Strike Variations in the Western Andean Mountain Front (20°30'-21°15'S)

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Recent advances in the knowledge of the forearc tectonic and structural evolution elucidate the strong control of the pre-orogenic structures in the accommodation of the Andean shortening. As have been shown in others orogens, the choice of the structural style can lead a difference of up to an order of magnitude in shortening estimations. Particularly in the Western Andean Mountain Front (WAMF), at 21°S, depending on the structure style selected, contrasting tectonic models have been proposed (crustal structures) to explain the Andean orogenesis. In order to assess the structural style and tectonic evolution, between 20°30'-21°15'S, we present a detailed 2D seismic interpretation calibrated by well and drill-hole data, and rock outcrops. Also, we perform isopach map and restored geological sections. The main results of this contribution reveal partially inverted graben and half-graben arrays formed by Jurassic to Early Cretaceous extension and subsequently underwent contraction which led the basin inversion at least since the Upper Cretaceous, developing hanging and footwall short-cut structures. Inverted syn-rift isopach map gives us the chance to propose lateral continuation of main structures and identify along strike variations, as tip points, polarity changes and accommodation zones, showing a pseudo-3D structural configuration for the WAMF. Most of the shortening estimations were close to 3 km, despite of along strike variations on main inverted graben and half-graben structures. Partially inverted graben and half-graben arrays, its evolution and along strike variations must be consider in future tectonic models to better understand the main Andean structures.