Thick-skinned tectonic style resulting from the inversion of previous structures in the southern Cordillera Oriental (NW Argentine Andes)

N. CARRERA* & J. A. MUÑOZ

Department de Geodinàmica i Geofísica, Institut de Recerca Geomodels, Facultat de Geologia, Universitat de Barcelona, Martí i Franquès s/n, 08028 Barcelona, Spain

**Corresponding author (e-mail: nuriacarrera@ub.edu)*

Abstract: Structures mapped in the southern Cordillera Oriental of the Andes show an unexpected geometry in an east–west cross-sectional view, with a remarkable predominance of west-directed thrusts. Although some of the Andean structures trend north–south perpendicular to the main east–west direction of Andean shortening, many of them clearly differ from this expected orientation. This peculiar structural style has been largely related to the inversion of the Cretaceous Salta Rift Basin; however, some of these anomalously trending Andean folds and faults do not result from the inversion of Cretaceous faults. This lack of inversion of some Cretaceous structures becomes evident where west-dipping extensional faults rest in the footwall of west-directed thrusts instead of developing east-directed thrusts, as would be expected. Detailed study of several structures and examination of the geometry and facies distribution of several basins highlight not only the role played by the inversion of Cretaceous extensional faults on the geometry of the Andean structures, but also that played by basement anisotropies on the development of both the Cretaceous extensional faults and the Andean contractional structures.

A complete understanding of the geological structure of a thrust and fold belt requires knowledge of several tectonic events that have shaped both the basement and the cover before the last contractional deformation.

Inversion tectonics has concentrated the geological community's attention since the 1980s when numerous papers defining most of the current concepts appeared (Bally 1984; Gillcrist *et al.* 1987; Cooper & Williams 1989). Most of the papers since have focused on the reactivation of the extensional systems that immediately predate the contractional deformation of orogenic systems. However, the influence that inherited anisotropies in the basement have played during the deformation of the rocks lying above is an ancient and recurrent idea among structural geologists (see Buchanan & Buchanan 1995 and Nemcok *et al.* 2005, and references therein). A problem arises in discriminating the role played by the different inherited fault systems and anisotropies at distinct structural levels during the evolution of orogenic systems that have experienced a protracted deformation history, such as is the case with the Andes. This issue has been addressed by numerous field-based studies in most of the orogenic systems of the Earth (Pyrenees, Garcia-Senz 2002; Andes, Kley *et al.* 2005; Carrera *et al.* 2006; Amilibia *et al.* 2008; Alps, Butler *et al.* 2006; Apennines, Scisciani 2009; Tavani *et al.* 2011) and also by analogue modelling (McClay & White 1995; Amilibia *et al.* 2008).

In the Cordillera Oriental of the Argentine Andes, the tectonic inversion of the Cretaceous Salta Rift basins has largely controlled the structural evolution of the Andean structures (Grier *et al.* 1991; Cristallini *et al.* 1997; Heredia *et al.* 1997; Rodríguez *et al.* 1999; Kley & Monaldi 2002; Kley *et al.* 2005; Carrera *et al.* 2006; Carrera & Muñoz 2008; Iaffa *et al.* 2011). Structural style, location and orientation of the structures, with many of them showing a trend departing from the regional north–south trend, perpendicular to the main Andean shortening, have been related to this tectonic inversion event. Alternatively, the intricate geometries of the Cordillera Oriental have also been explained as the result of superimposed contractional phases with distinct orientations (Marrett *et al.* 1994). Nevertheless, none of these ideas explain some of the structures observed in the southern Cordillera Oriental as well as major features of its structural grain (Carrera *et al.* 2006; Carrera & Muñoz 2008). The present study aims to suggest that the reactivation of anisotropies in the basement rocks may have played a significant role not only in the location and geometry of the Cretaceous extensional faults but also in the Andean contractional structures. A problem arises with the relative role played by the different structural anisotropies at different structural levels during the Andean deformation. This is a challenging concept given the limited amount of knowledge available on the internal

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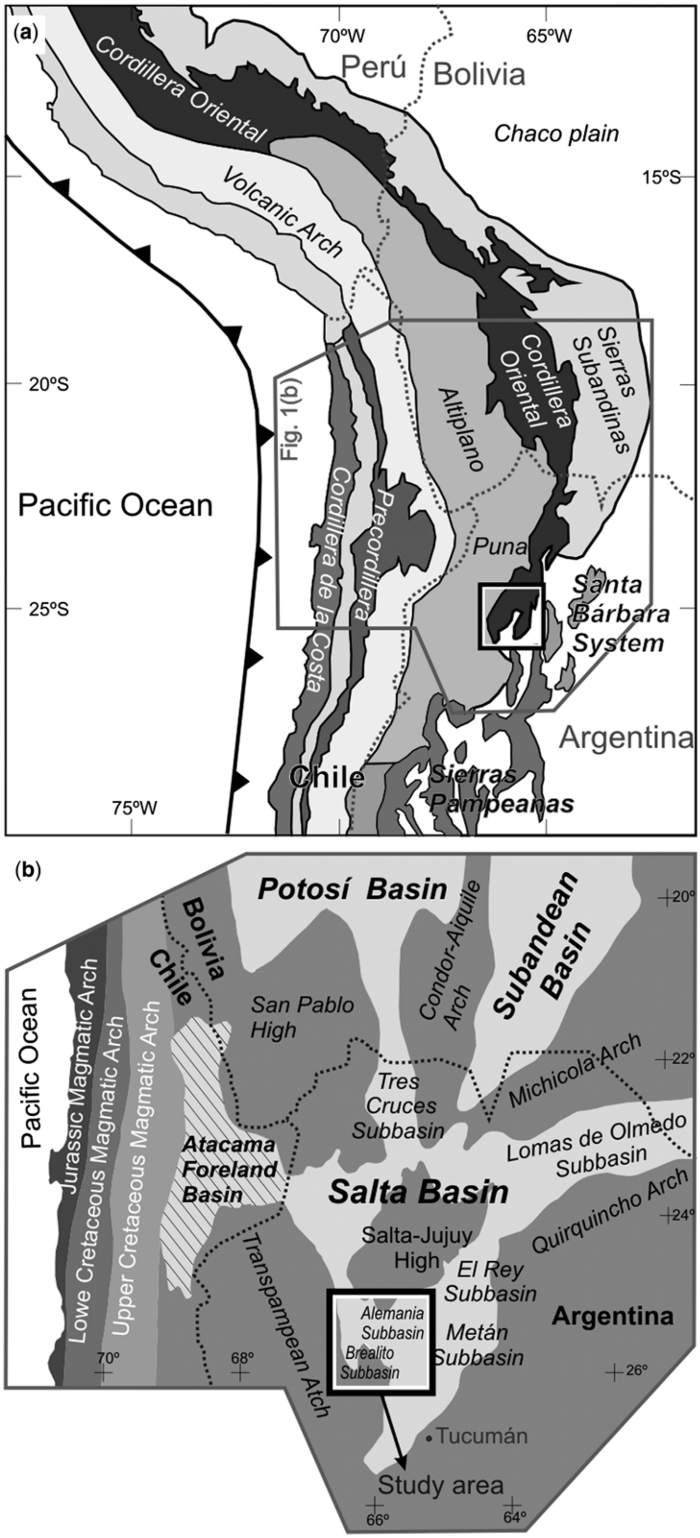


(a)
70ºW
65ºW
Perú
Bolivia
Chaco plain
15ºS
Cordillera Oriental
Volcanic Arch
Sierras Subandinas
Cordillera Oriental
20ºS
Altiplano
Fig. 1(b)
Pacific Ocean
Cordillera de la Costa
Precordillera
Puna
Santa Bárbara System
25ºS
Argentina
Chile
Sierras Pampeanas
75ºW
(b)
Potosí Basin
Subandean Basin
20º
Bolivia
Chile
Condor-Aiquile Arch
Pacific Ocean
Jurassic Magmatic Arch
Lowe Cretaceous Magmatic Arch
Upper Cretaceous Magmatic Arch
San Pablo High
22º
Michicola Arch
Tres Cruces Subbasin
Lomas de Olmedo Subbasin
Atacama Foreland Basin
Salta Basin
Quirquincho Arch
24º
Salta-Jujuy High
El Rey Subbasin
Transpampean Atch
Alemania Subbasin
Brealito Subbasin
Metán Subbasin
Argentina
70º
68º
26º
Tucumán
Study area
66º
64º

structure of basement rocks in the southern Cordillera Oriental.

This study provides new detailed maps and cross-sections of selected areas, as well as a collection of schematic palaeogeographical maps of the different stratigraphic units, which together with the detailed study of several structures suggest new ideas on the above-mentioned ideas. This field-based study takes advantage of the excellent outcrops of the southern Cordillera Oriental. Even so, we have incorporated available satellite images and aerial photographs to further constrain the geological mapping and structural interpretation. The good exposure provides an excellent field laboratory in which to study in detail the geometrical features of structures that have been mainly described from seismic data.

Geological setting

The study area pertains to the southern Cordillera Oriental of the Central Andes, east of the Puna, north of the Sierras Pampeanas and west of the Santa Bárbara System (Fig. 1).

Stratigraphy

The southern Cordillera Oriental presents extensive outcrops of Precambrian basement rocks, and irregularly distributed continental Mesozoic and Tertiary sediments (3–12 km thick) (Figs 2 & 3). The Palaeozoic mainly consists of plutonic bodies, which intruded into the Precambrian rocks (Fig. 3). The distribution of these units results from the superposition of different tectonic events that have affected the area since Palaeozoic times: Early Palaeozoic deformation events, Ordovician Ocloyic Orogeny, Cretaceous Salta Rift and Cenozoic Andean Orogeny (Salfity & Marquillas 1981; Mon & Hongn 1991; Hongn & Becchio 1999; Becchio *et al.* 2008).

Basement. In this study, basement is defined as all the rocks formed prior to the Cretaceous extension and it consists of metamorphic rocks intruded by several plutonic suites (Fig. 3).

Most of the metamorphic rocks of the southern Cordillera Oriental belong to the Precambrian–Lower Cambrian Puncoviscana Formation (Turner 1960) (Fig. 3). It consists of a thick turbiditic succession of shales and sandstones with low-grade metamorphism (Buatois & Mángano 2003; Aceñolaza 2004). These rocks present an intense deformation and their grade of metamorphism increases westwards, becoming the phyllites and mottled schists of the La Paya Formation (Aceñolaza *et al.* 1976) (Fig. 3).

Several plutons have intruded these metamorphic rocks through time, mainly present in the western parts of the study area (Fig. 3). These are the trondhjemites, granites and granodiorites of the Cachi Formation (Precambrian) (Galliski 1981, 1983*a*, *b*; Toselli 1992), the medium to fine-grained granite of the Alto del Cajón (Cambro-Ordovician) (Oyarzábal 1989), and the coarse-grained granites and granodiorites of the Ordovician plutons.

Syn-rift and post-rift (Salta Group). The Cretaceous–Lower Eocene Salta Group (Turner 1959) is the oldest succession unconformably overlying the basement rocks (Fig. 3). It accumulated into the Salta Basin, and recorded a sedimentary and volcanic evolution controlled by its extensional regime (Reyes *et al.* 1976; Salfity & Marquillas 1986) (Figs 1 & 3). The Salta Group comprises three subgroups, which from bottom to top are (Fig. 3): Pirgua; Balbuena; and Santa Bárbara (Moreno 1970; Reyes & Salfity 1973; Salfity & Marquillas 1981; Gómez-Omil *et al.* 1989).

The Pirgua Subgroup (Vilela 1951; Reyes & Salfity 1973) corresponds to the syn-rift sequence, related to the extensional event that formed the Salta Basin (Fig. 3). This basin shows a complex geometry characterized by sub-basins with different trends around an uplifted area, the Salta–Jujuy High (Fig. 1). The Pirgua Subgroup consists of a red continental succession of breccias, conglomerates, sandstones and shales with volcanic rock intercalations, corresponding to fluvial and alluvial deposits (Sabino 2002).

The Balbuena Subgroup corresponds to the post-rift succession related to the initial stages of thermal subsidence (Marquillas *et al.* 2005). It includes the carbonate sandstones of the Lecho Formation (Maastrichtian) (Turner 1959) and the limestones of the Yacoraite Formation (Maastrichtian–Danian) (Turner 1959) (Fig. 3).

The Santa Bárbara Subgroup represents the thickest post-rift succession. It is composed of orange fluvial breccias, sandstones and shales of the Mealla Formation (del Papa & Salfity 1999), the white or green lacustrine sandstones, shales and limestones of the Maíz Gordo Formation, and the red shales and sandstones of the Lumbrera Formation (Fig. 3).

Fig. 1. (**a**) Structural units of the Central Andes where the study area is located (black square). Modified from Coutand *et al.* (2001) and Amilibia (2002). (**b**) The Cretaceous Salta Basin highlights because of its shape with differently oriented arms around the Salta–Jujuy structural high. The black square corresponds to the study area. Modified from Viramonte *et al.* (1999).

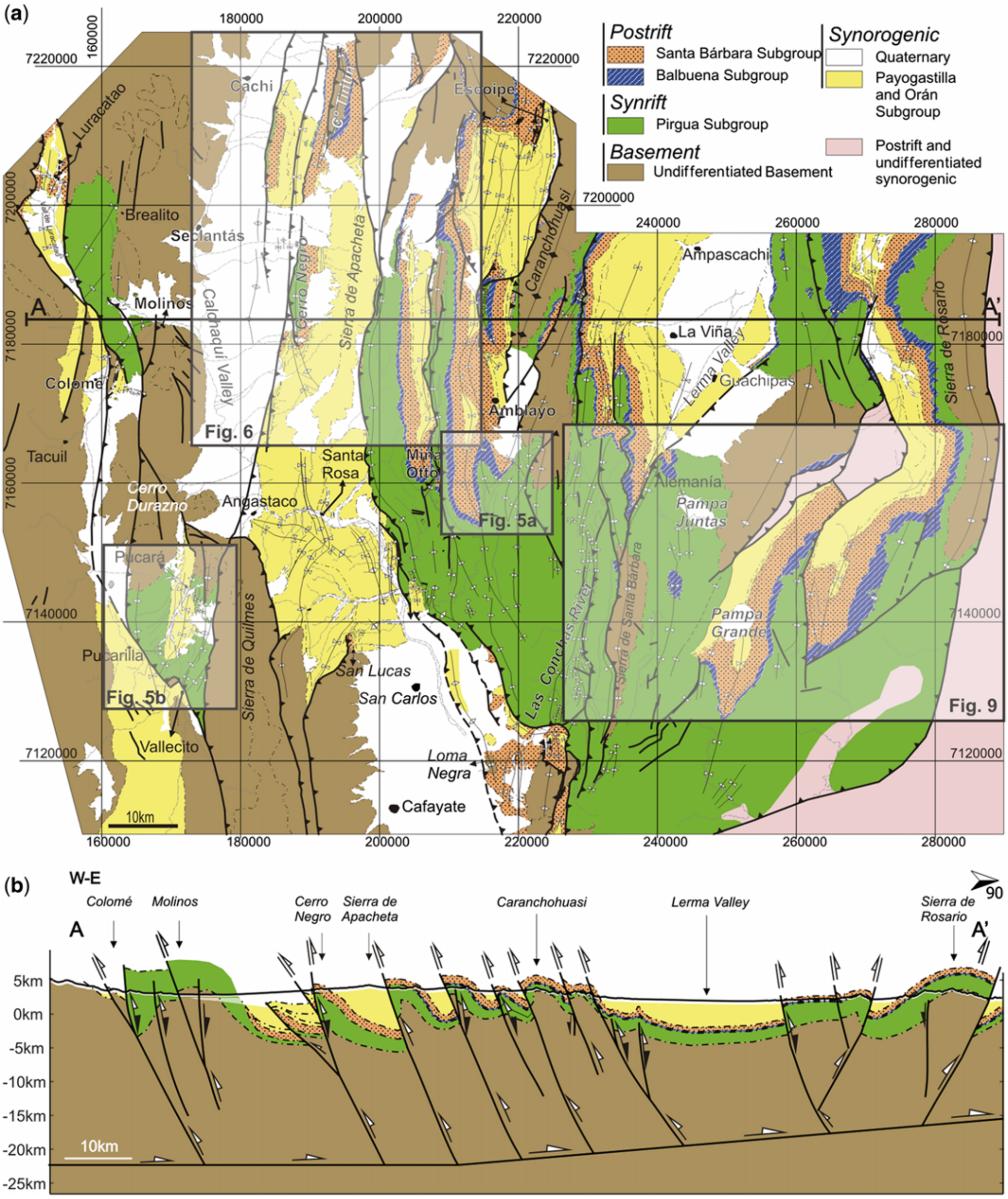


Fig. 2. (**a**) Geological map of the southern Cordillera Oriental where the main tectonostratigraphic units are represented. Black squares correspond to the areas considered in this paper. Co-ordinates are UTM from the 20j zone. Modified from Carrera *et al.* (2006) and Carrera & Muñoz (2008). (**b**) General cross-section A–A′ across the southern Cordillera Oriental from Molinos to the Sierra de Rosario. Tight asymmetric folds dominate the tectonic style of the area. These folds are related to high-angle basement-involved thrusts, showing inverted limbs in the hanging-wall anticlines. These features and the presence of synclines next to the thrusts in the footwall constrain the maximum displacement of thrusts. See (a) for the location.

Syn-orogenic (Payogastilla and Oran groups). The syn-orogenic sediments of the southern Cordillera Oriental correspond to the proximal facies of the Payogastilla Group (Díaz & Malizzia 1984) and to the distal sequences of the Oran Group, which are laterally equivalent to the upper Payogastilla formations (Russo & Serraiotto 1978). Both groups are subdivided from bottom to top into the Metán

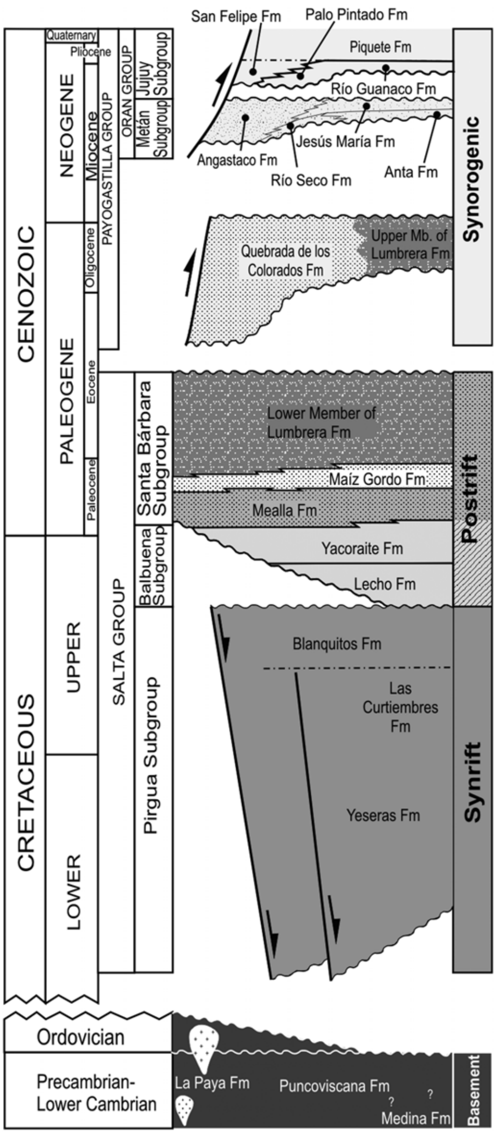


Fig. 3. Chronostratigraphic diagram showing the main tectonostratigraphic units of the study area, as well as the main tectonic events that controlled their deposition. Formations cropping out in the area have been represented: a wavy line depicts the major unconformities bounding the main units, whereas a dash-dot line represents minor internal unconformities. Modified from Carrera & Muñoz (2008).

Subgroup and the Jujuy Subgroup (Gebhard *et al.* 1974) (Fig. 3). The sandstones and conglomerates of the Quebrada de los Colorados Formation correspond to the lower succession of the proximal synorogenic sediments, which grade distally into the shales of the upper Lumbrera Formation (Fig. 3). The fluvial and alluvial conglomerates and sandstones of the Angastaco Formation, the eolian sandstones of the Río Seco Formation and the lacustrine shales of the Anta Formation (Fig. 3) (Russo & Serraiotto 1978; Galli 1995) form the Metán Subgroup. The Jujuy Subgroup corresponds to the upper part of synorogenic sediments, which consists of the alluvial conglomerates of the San Felipe Formation and the Piquete Formation, the sandstones and shales of the Palo Pintado Formation, and the sandstones and conglomerates of the Guanaco Formation (Fig. 3) (Gebhard *et al.* 1974; Russo & Serraiotto 1978; Starck & Vergani 1996). Over this succession, Quaternary sediments show growth geometries implying that they are also syn-orogenic sediments (Carrera & Muñoz 2008).

Growth geometries and unconformities described for the syn-orogenic sediments of the study area, as well as fission-track data analysis made on these sediments, demonstrate an eastwards propagation of the Andean deformation (Carrera & Muñoz 2008; Carrera 2009; Carrapa *et al.* 2011). The lower syn-orogenic sediments were deposited within a continuous foreland basin in middle Eocene–Oligocene times, which broke in middle Miocene times and triggered a set of disconnected intramontane basins from Late Miocene times until Recent (Carrera & Muñoz 2008; Carrera 2009; Hain *et al.* 2011).

General cross-section

A general cross-section of the southern Cordillera Oriental shows basement-involved structures with a double vergence. It is worth noting the predominance of west-directed thrusts, their steep dips and the relatively thin basement-involved thrust sheets. At the surface, fault-related folds with short overturned thin forelimbs and long steeply to moderately dipping back limbs characterize the structural style of the area (Fig. 2). The area width where such very steep thrusts are present suggests that thrusts have relatively steep trajectories down into the upper crust. These thrusts have been interpreted as merging downwards into a regional detachment (Cladouhos *et al.* 1994; Kley & Monaldi 2002; Carrera *et al.* 2006; Carrapa *et al.* 2011). However, the location and geometry of such detachment is speculative given the absence of geophysical data. A simple calculation of the excess of the structural area along the cross-section gives a detachment depth of 20 km. In the eastern part of the section, the Metán Basin, the detachment location has been estimated at about 15–16 km (Cristallini *et al.* 1997). This shallower depth would suggest a deeper detachment below the Puna thrust front and, consequently, a detachment dipping slightly to the west. Such a dip is consistent with the

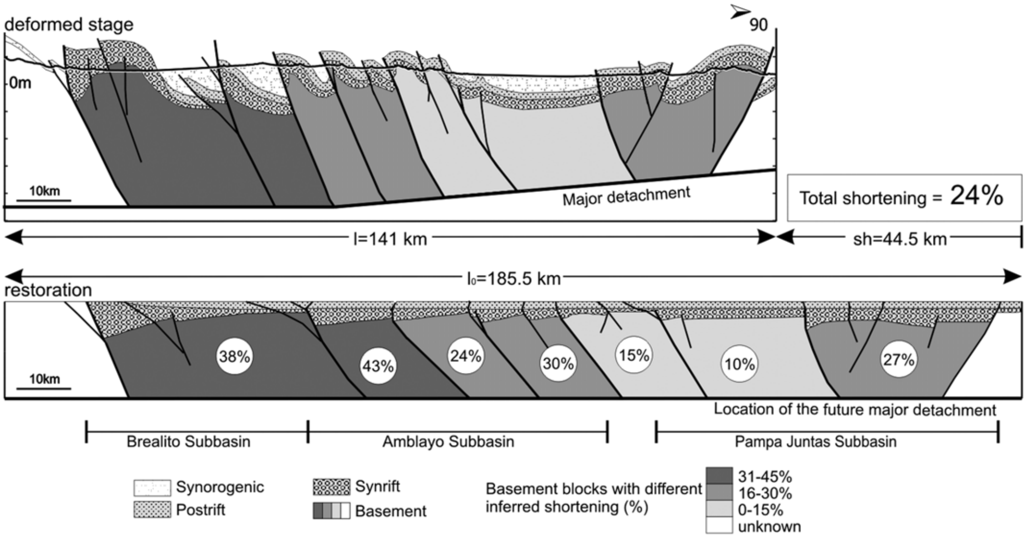


Fig. 4. Balanced cross-section of the general cross-section A–A′ shown in Figure 2b. Flexural-slip restoration (constant length of lines) has been applied for the bottom of the syn-orogenic, the post-rift and the syn-rift units. However, basement blocks have been restored by constant area due to its internal deformation and the absence of stratigraphic references. The general shortening is 24% but the inhomogeneous distribution of the shortening, which is higher in the borders of the main extensional basin, mainly in the western margin must be emphasized.

west-dipping regional elevation of the bottom of the syn-orogenic sequence connecting the synclinal hinges (Fig. 4). Moreover, the detachment below the Puna could be located at the low-velocity zone, at about 25 km depth, as deduced from seismic data in the central Puna (ANCORP Working Group 2003). This west-dipping detachment has been assumed to be parallel to the Moho, as suggested by the available geophysical data (Muñoz *et al.* 2005), and, as a consequence, it has been restored to the horizontal. The restoration of the regional cross-section highlighted a change in the detachment dip around the Calchaquí Valley (Figs 2 & 4).

The amount of Andean shortening has been calculated, using ‘flexural-slip restoration’ of the base of the Angastaco Formation, at 44.5 km. This represents a 24% shortening (Fig. 4). However, shortening of the southern Cordillera Oriental is not homogeneously distributed, the maximum occurring around the Calchaquí Valley (*c.* 40%) and the minimum around the Lerma Valley (*c.* 10%) (Fig. 4).

The shortening measured by flexural-slip restoration of the base of the syn-orogenic sediments for the whole Andean Orogeny is around 108 km at this latitude (Muñoz *et al.* 2005). Thus, the shortening found in the study area represents about 41% of the total shortening of the Andes at this latitude, whereas its length is less than 20%.

The tight geometry of the thrust-related folds in the Mesozoic–Cenozoic sedimentary beds implies that the involved basement has been internally deformed. We do not know the deformation mechanisms involved in the basement, although outcrop observations suggest that fold tightening and reactivation of older structural fabrics may account for the shortening estimates. Owing to this internal deformation and the absence of stratigraphic references, the basement has been restored by ‘constant area restoration’.

Detailed structure

While several authors have described the main structural features of the southern Cordillera Oriental (Grier *et al.* 1991; Mon & Salfity 1995; Cristallini *et al.* 1997; Carrera *et al.* 2006; Carrera & Muñoz 2008), here we present new detailed descriptions of several structures of this area. Nevertheless, and for the consistency of this paper, we also include two previously described key localities: Amblayo–Ayuso (Carrera *et al.* 2006) and Pucará–Vallecito (Carrera & Muñoz 2008).

Amblayo–Ayuso

The Amblayo–Ayuso area is located in the central part of the southern Cordillera Oriental (Figs 2 & 5). Southeast of Amblayo, a preserved extensional structure is observed, where folded Pirgua beds define a fan geometry with an eastwards expansion

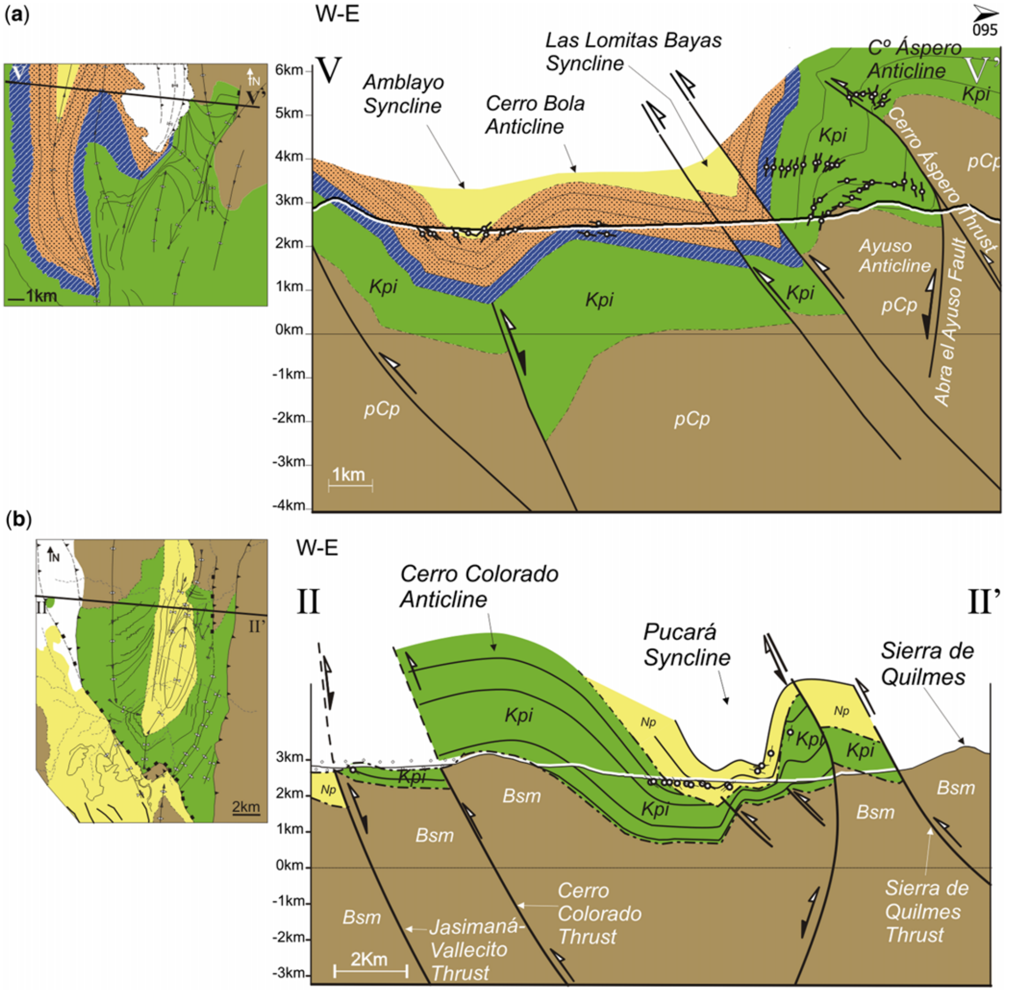
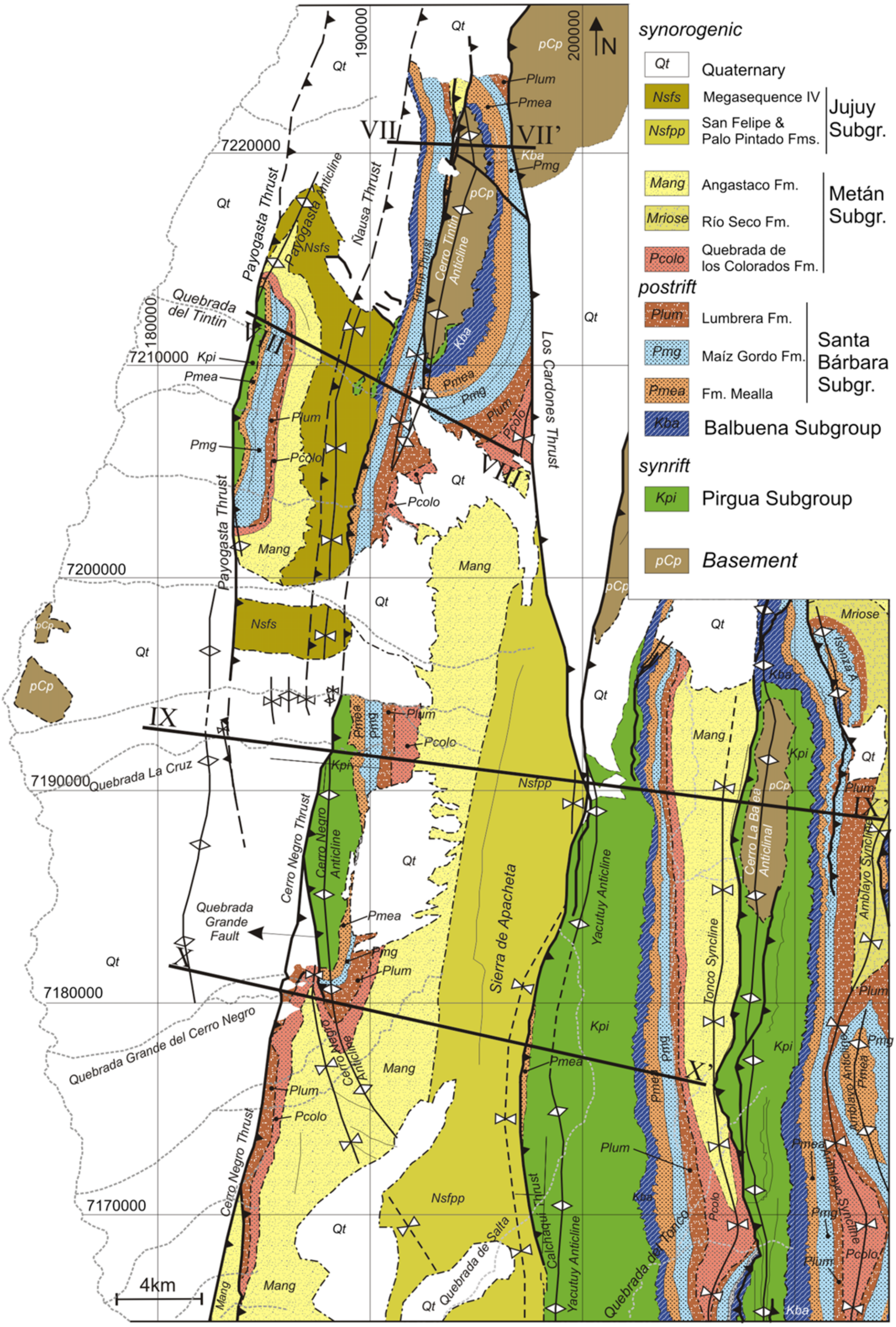


Fig. 5. (**a**) Cross-section V–V′ of the Amblayo–Ayuso area where a rollover anticline related to an originally west-dipping extensional fault is preserved. The extensional fault is folded in the footwall of a west-directed thrust and only moderately reactivated. See Figure 2a for the location and legend. Modified from Carrera *et al.* (2006). (**b**) Cross-section II–II′ of the Pucará area, which provides evidence of tectonic inversion. However, a folded west-dipping extensional fault is also present. See Figure 2a for the location and legend. Modified from Carrera & Muñoz (2008).

of sediments towards a west-dipping NNE–SSW extensional fault, the Abra el Ayuso Fault (Carrera *et al.* 2006; Carrera 2009) (Fig. 5). This structure is located in the footwall of a west-directed thrust, the Cerro Áspero Thrust, which carries basement rocks on top of Pirgua sedimentary rocks (Fig. 5). Regardless of its favourable orientation, the Abra el Ayuso extensional fault was not reactivated during the forward propagation of the Andean deformation during Neogene times. Instead, the extensional fault has been folded and truncated in the footwall of a backthrust and only partially reactivated along a portion, once folding reversed the dip.

Pucará–Vallecito area

The Pucará–Vallecito area is located at the western margin of the southern Cordillera Oriental (Figs 2 & 5). Here, the Jasimaná–Vallecito Thrust represents the SW margin of the Pirgua syn-rift basin, as demonstrated by the absence of Pirgua sediments in its footwall, while in the hanging wall it is up to 4 km thick (Fig. 5). This thrust corresponds to an


synorogenic
Qt Quaternary
Nsfs Megasequence IV
Nsfpp San Felipe & Palo Pintado Fms.
Jujuy Subgr.
Mang Angastaco Fm.
Mriose Río Seco Fm.
Pcolo Quebrada de los Colorados Fm.
Metán Subgr.
postrift
Plum Lumbrera Fm.
Pmg Maíz Gordo Fm.
Pmea Fm. Mealla
Santa Bárbara Subgr.
Kba Balbuena Subgroup
synrift
Kpi Pirgua Subgroup
pCp Basement
N
190000
200000
180000
7220000
7210000
7200000
7190000
7180000
7170000
VII
VII'
VIII
VIII'
IX
IX'
X
X'
Payogasta Thrust
Payogasta Anticline
Ñausa Thrust
Cerro Tintin Anticline
Quebrada del Tintin
Los Cardones Thrust
Quebrada La Cruz
Cerro Negro Thrust
Cerro Negro Anticline
Quebrada Grande Fault
Quebrada Grande del Cerro Negro
Sierra de Apacheta
Yacutuy Anticline
Calchaquí Thrust
Quebrada de Salta
Quebrada del Tonco
Tonco Syncline
Cerro La Bayo Anticlinal
Amblayo Syncline
Amblayo Anticline
4km

inverted Cretaceous extensional fault, corroborated by the presence of coarse facies of Pirgua sediments along the thrust as well as in basement shortcuts in its hanging wall (Carrera & Muñoz 2008).

East of the Pucará Valley, folded Pirgua beds are found in the hanging wall of a preserved west-dipping extensional fault, which have been partially reactivated and folded in the footwall of the west-directed Sierra de Quilmes Thrust (Fig. 5). This structure resembles the one described in the Amblayo–Ayuso area, and confirms the non-reactivation of favourably oriented extensional faults and their folding and truncation by east-dipping backthrusts.

North Calchaquí Valley area

Description. The north Calchaquí Valley area comprises the region from the Calchaquí River to the west (from north of Cachi to north of Angastaco) to the Amblayo Valley to the east (Figs 2 & 6). This area is dominated by north–south-trending west-verging folds, which involve the entire lithological succession, from basement to Quaternary rocks (Figs 2 & 6).

The Cerro Tintin Anticline, located east of Cachi, is the northernmost mapped fold in this area. This anticline trends NNE–SSW and is cored by basement rocks (Figs 6 & 7). In its southern termination, basement rocks are overlain by a thin syn-rift sequence, which disappears to the north (pinch-out) where a complete and thick post-rift succession directly overlies the basement rocks of the Salta–Jujuy High (Figs 6 & 7).

The Cerro Tintin Anticline is located in the hanging wall of a main west-directed thrust, the Cerro Tintin Thrust, which in its central part carries basement rocks on top of the complete post-rift sediments in its footwall (Fig. 6). Towards the south, the displacement of this thrust progressively diminishes until it disappears at the surface (Figs 6 & 7).

West of the Cerro Tintin, the NNE–SSW-trending Payogasta west-directed thrust crops out carrying syn-rift sediments on top of Cenozoic and Quaternary syn-orogenic sediments (Figs 6 & 7) (see fig. 13 of Carrera & Muñoz 2008). In the hanging wall of this thrust, the Balbuena Subgroup is absent, as the syn-rift sediments are directly overlain by the sandstones of the Mealla Formation. The Payogasta Anticline developed in the hanging wall of the Payogasta Thrust, and shows trend variations from NNE–SSW in the north to NNW–SSE in the south.

The syn-rift Pirgua sediments show a significant difference in thickness and facies at both sides of the Cerro Tintin Thrust. The minimum observed thickness in the footwall is 1.5 km (the bottom does not outcrop), whereas, in the hanging wall, the maximum observed thickness is about 250 m. The footwall is characterized by Pirgua coarse proximal facies (conglomerates and sandstones with intercalated levels of breccias), mainly next to this thrust.

Southwards, the Cerro Negro Anticline folds syn-rift, post-rift and syn-orogenic sediments. This fold has a north–south trend to the north, which changes to a NNW–SSE trend southwards (Fig. 6). This anticline is located in the hanging wall of the west-directed Cerro Negro Thrust, which carries syn-rift sediments on top of a thick sequence of Quaternary gravels (Figs 6, 7 & 8a). The displacement of this thrust diminishes towards the north where it disappears near the area where the Cerro Tintin Thrust also disappears (Fig. 6).

Conglomerates of the Pirgua Subgroup crop out in the core of the Cerro Negro Anticline, followed by a thick succession of post-rift and syn-orogenic subparallel beds (Fig. 6). Here, as occurs in the hanging wall of the Payogasta Thrust, the Mealla Formation (Santa Bárbara Subgroup) directly overlies the Pirgua Subgroup and the sediments of the Balbuena Subgroup are absent (Figs 7 & 8).

In the central parts of the Cerro Negro Anticline, a thrust splay merges into the Cerro Negro Thrust. It shows a NNW–SSE trend and a high-angle dip, and has been named the Quebrada Grande Fault (Fig. 6). In the Quebrada Grande, this fault carries the rocks of the Maíz Gordo Formation (Santa Bárbara Subgroup) of the Cerro Negro Anticline's western limb on top of the lower syn-orogenic sediments, which in turn are folded by a syncline (Figs 6, 7d & 8c). In the same area, the Cerro Negro Thrust presents a lower dip angle (Figs 6 & 8b). North of the Cerro Negro Anticline, the Cerro Negro Thrust shows a higher angle than in the south (Fig. 8).

West of the Cerro Negro Thrust, Quaternary sediments located in its footwall are deformed and show growth geometries with a sedimentary expansion towards the west (Fig. 7) (Carrera & Muñoz 2008). These sediments are folded by two anticlines; one of them having an associated backthrust (Fig. 7).

Eastwards of the previously described structures, the west-directed Calchaquí Thrust carries syn-rift

Fig. 6. Geological map of the northern Calchaquí Valley area. Syn-rift thickness is variable, increasing towards the south. The Balbuena Subgroup is less extensive than the Santa Bárbara Subgroup. Moreover, the presence of a thick Quaternary package in the western side must be highlighted because in the eastern areas it is nearly absent. See Figure 2a for the location. Co-ordinates are UTM from the 20j zone.

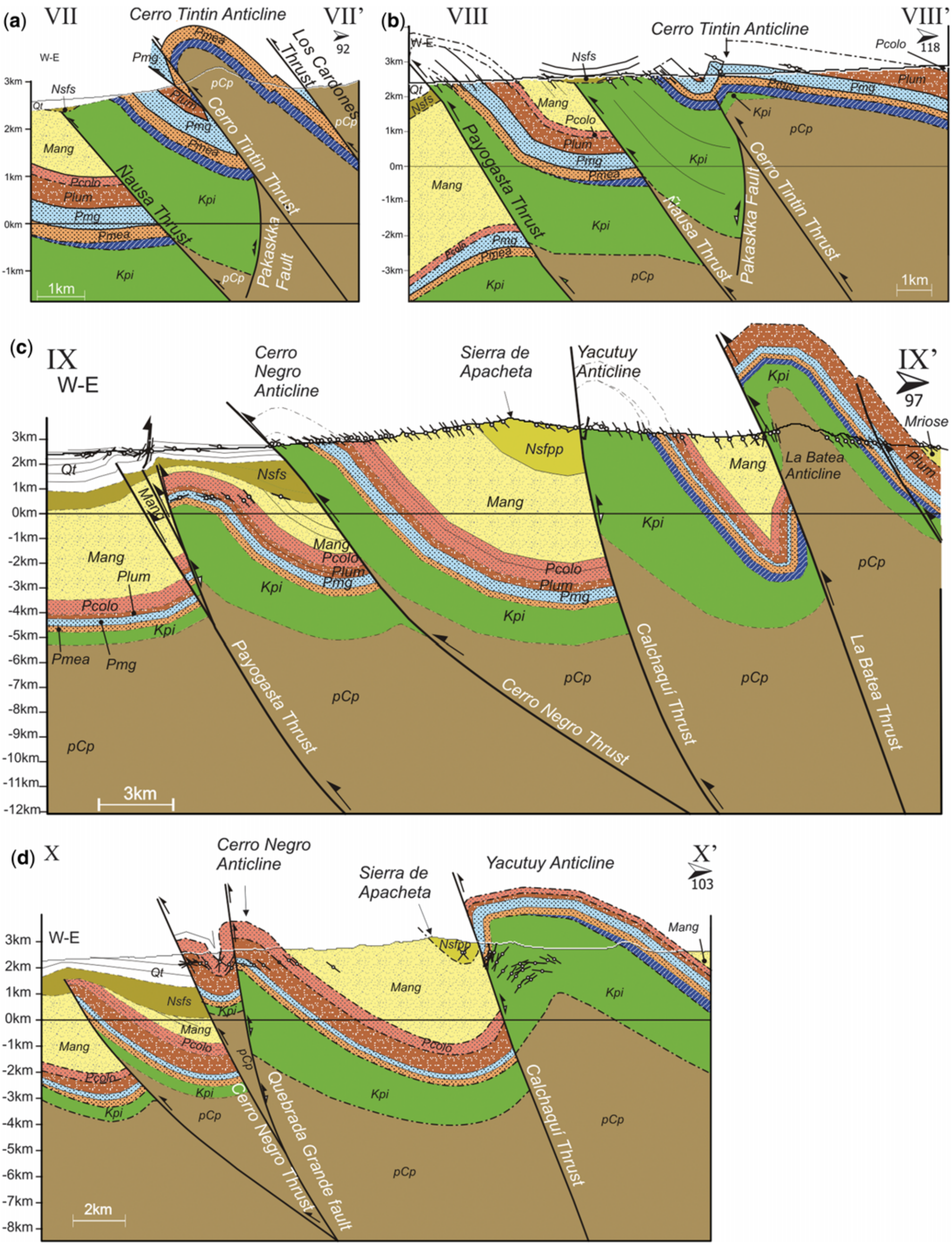


Fig. 7. Detailed geological cross-sections across the north Calchaquí area. See Figure 6 for the location and legend. (**a**) Geological cross-section VII–VII′ across the northern part of the Cerro Tintin. The absence of Pirgua sediments in the hanging wall of the Cerro Tintin Thrust, and the presence of these sediments in the footwall, suggests the presence of a west-dipping extensional fault at depth. (**b**) Geological cross-section VIII–VIII′ across the southern termination of the Cerro Tintin. (**c**) Geological cross-section IX–IX′ across the northern part of the Cerro Negro. Here, the Cerro Negro Thrust corresponds to a bypass structure related to the Quebrada Grande Fault. (**d**) Geological cross-section X–X′ across the southern termination of the Cerro Negro. Here, the Cerro Negro Thrust corresponds to a shortcut structure related to the Quebrada Grande Fault.

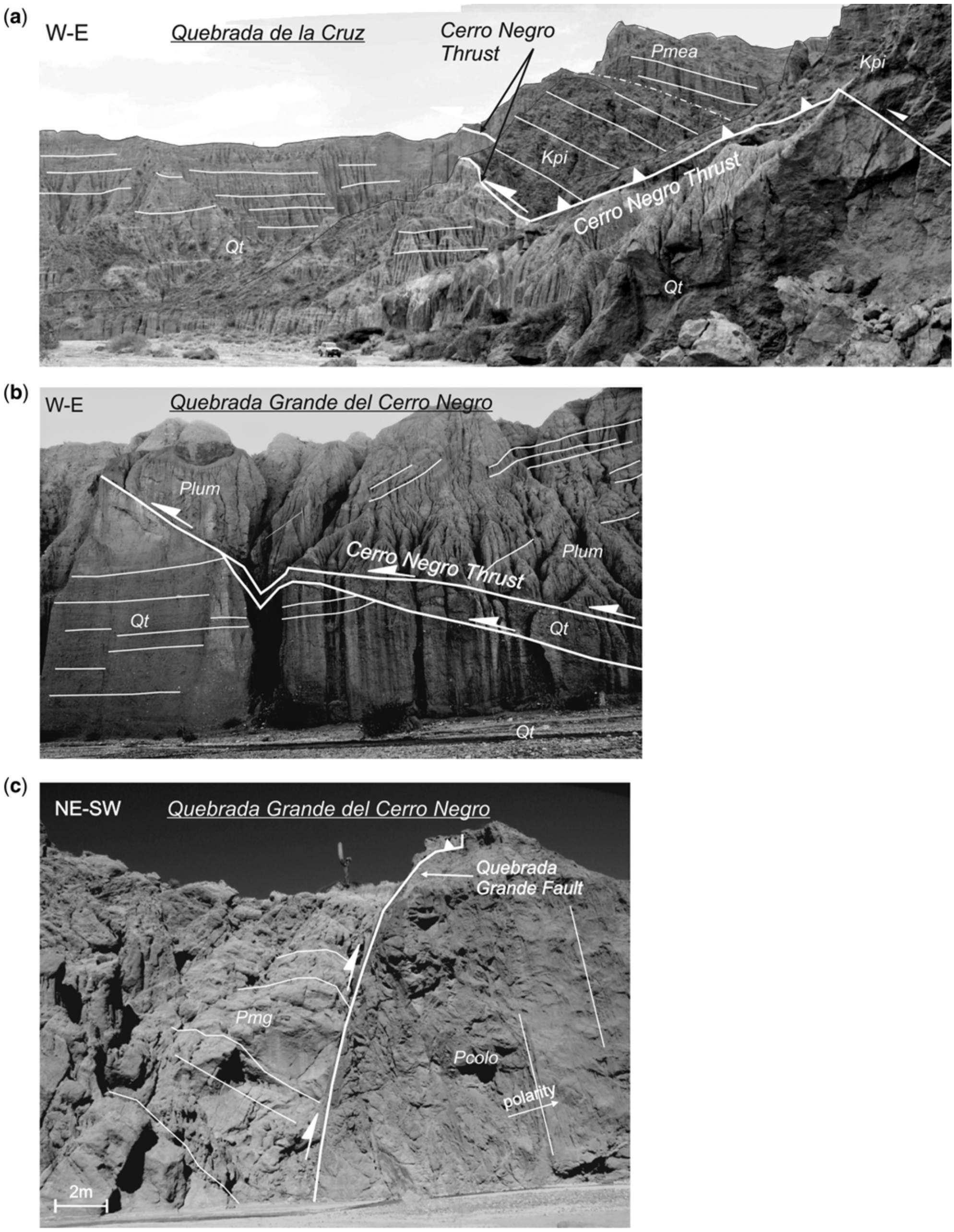


Fig. 8. (**a**) Field shot of the Cerro Negro Thrust in the Quebrada la Cruz. Note the moderate dip angle of this thrust in the area. In its hanging wall, sediments of the Mealla Formation (Santa Bárbara Subgroup) are lying directly on top of syn-rift sediments, constraining the depositional basin of the Balbuena Subgroup. In the footwall, Quaternary sediments hundreds of metres thick are present. (**b**) Field shot of the Cerro Negro Thrust in the Quebrada Grande of the Cerro Negro. Here, post-rift sediments of the Lumbrera Formation are thrusting a thick succession of Quaternary sediments. Note the low-angle dip of the Cerro Negro Thrust in this area. (**c**) Field shot of the Quebrada Grande Fault in the Quebrada Grande of the Cerro Negro. Sediments of the Maíz Gordo Formation involved in the Cerro Negro Anticline are thrusting through a high-angle dip fault on top of the lowermost syn-orogenic sediments. These relationships, together with the facies distribution described for the Cerro Negro, suggest the inversion of an extensional fault, the Quebrada Grande Fault.

and post-rift sediments over onto of syn-orogenic ones (Figs 6 & 7). In its hanging wall, the syn-rift sediments are thicker than 3 km and are folded by the Yacutuy Anticline. Here, the Pirgua Subgroup shows a rapid change of facies from breccias to sandstones towards the east. Above, the Balbuena Subgroup is well developed in the eastern limb of the anticline, but it is absent in its western limb below the Santa Bárbara Subgroup sediments (Figs 6 & 7).

East of the Yacutuy Anticline and in the footwall of the west-directed thrust La Batea Thrust, the Tonco Syncline folds post-rift and syn-orogenic sediments (Figs 6 & 7). In its hanging wall, syn-rift sediments are folded by the La Batea Anticline, which shows a subvertical to overturned frontal limb and a high dip angle back-limb (Fig. 7). The basement rocks of the La Batea Anticline core crop out in its central part, whereas, southwards, and westwards in the Yacutuy Anticline, the thickness of the Pirgua Subgroup sediments increases, preventing the outcrop of basement rocks (Figs 6 & 7).

Interpretation. Most of the described geometries, facies distributions of the syn-rift sediments, and the relationships between structures and different sedimentary packages denote the tectonic inversion of the Pirgua Cretaceous extensional basins. In the north Calchaquí Valley area, several Cretaceous extensional faults can be deduced. The SW faults would have a NNW–SSE trend forming a left-lateral stepped extensional fault system, with the main transfer zone located between the terminations of the Cerro Negro and Payogasta anticlines. These faults would be part of the Salta Rift Basin western margin. The northern extensional fault has been derived by the thickness and facies distribution of the syn-rift sediments in the footwall of the Cerro Tintin Thrust. A dip to the west of this fault can be inferred, although there are no constraints to knowing its trend (a north–south to NNE–SSW strike has been assumed). It has been named the Pakaskka Fault, which in Quechua means hidden, and would represent the western boundary of the Salta–Jujuy High.

The Quebrada Grande Fault represents a portion of a reactivated NNW–SSE extensional fault, as suggested by its high dip angle and its orientation parallel to the main extensional faults described in the western parts of the southern Cordillera Oriental (Pucará–Vallecito: Carrera & Muñoz 2008; and Molinos–Luracatao: Carrera *et al.* 2006). The low dip angle Cerro Negro Thrust, westwards of the Quebrada Grande Fault, would represent a shortcut into its footwall (Fig. 7d).

The structure and sedimentary expansion of the Quaternary sediments described for the footwall of the Cerro Negro Thrust is related to the existence of a thrust at depth that controlled their deposition and the geometry of their beds (Fig. 7c). This thrust should correspond to the continuation towards the south of the Payogasta Thrust. The change in the orientation of the Payogasta Anticline at the surface would indicate the reactivation of a NNW–SSE-trending extensional fault.

The syn-rift facies distribution described in the Yacutuy Anticline, where grain size increases towards the west, suggests the presence of an extensional fault located to the west of this anticline. This fault controlled their deposition and has been partially reactivated by the Calchaquí Thrust (Figs 6 & 7).

As in the Amblayo–Ayuso area, the Pakaskka extensional fault has been folded in the footwall of a west-directed thrust. The location at depth of the Pakaskka Fault would have probably controlled the relay area between the Cerro Tintin Thrust and the Cerro Negro Thrust.

Thickness variations of the post-rift sediments, which increase towards the north and the east, indicate that the Salta–Jujuy high was part of the extensional basin as it was subjected to the thermal subsidence inside the boundaries of the basin. From the aforementioned descriptions, the Balbuena Subgroup presents a western depositional margin with a NW–SE trend, parallel to the main rift-margin extensional faults, a location which is well constrained in the field (Fig. 6).

Alemania–Pampa Juntas–Acosta Valley area

Description. The Alemania–Pampa Juntas–Acosta Valley area shows structures with a wide range of orientations and vergences (Figs 2 & 9). In the western part, structures verge to the west, and the dominant ones are those trending north–south and NNW–SSE. In the eastern part of this area, structures verge to the east and are NE–SW trending, although they also interfere with some north–south-trending structures. The structures located at the eastern boundary of the southern Cordillera Oriental, next to the Santa Bárbara System, are NNE–SSW trending and verge to the east (Fig. 9).

In the NW margin of this area, a pair of NNW–SSE-trending west-directed thrusts crop out (Fig. 9). The western one, a high-angle dipping thrust, carries a thick syn-rift sequence in its hanging wall. These rocks and the overlying post-rift succession are folded by an anticline. The eastern flank of this fold is affected by the second thrust, which is also west-directed but presenting a lower dip angle. This thrust duplicates the post-rift series cutting the upper part of the syn-rift sediments (Fig. 9).

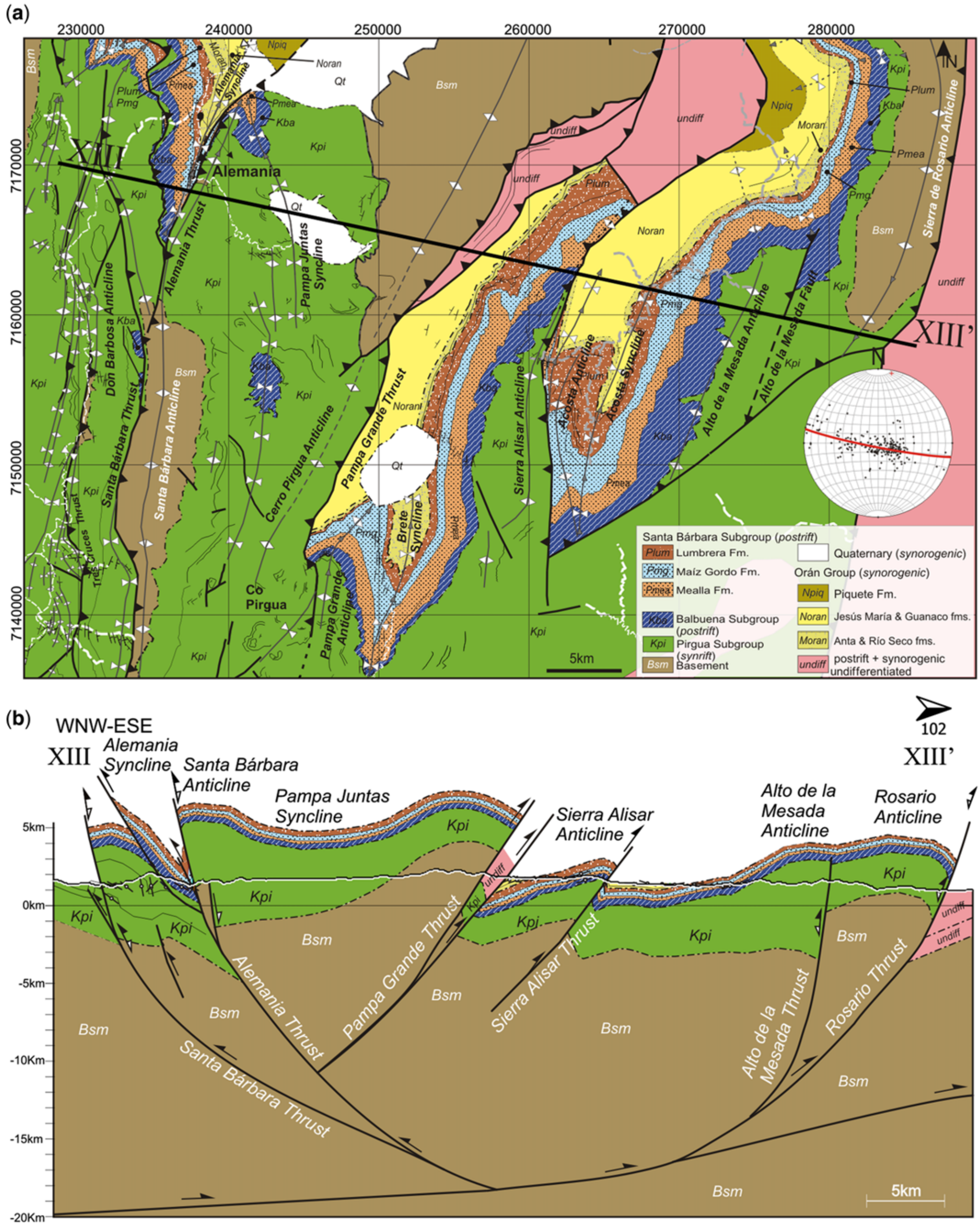


Fig. 9. (**a**) Geological map of the Alemania–Pampa Juntas–Acosta Valley area. The dominant orientation of the structures must be highlighted: on the eastern side they are NE–SW, whereas in the west they are north–south or NNW–SSE. Moreover, sediments of the Pirgua Subgroup show a variable thickness depending on the location. See Figure 2a for the location. (**b**) Geological cross-section XIII–XIII′ of the Alemania–Pampa Juntas–Acosta Valley area. Inverted extensional structures have been found in this area. See (a) for the location. Co-ordinates are UTM from the 20j zone.

East of Alemania, the NNE–SSW-trending and west-directed Alemania Thrust crops out (Fig. 9). Southwards, its displacement diminishes as the Santa Barbara Thrust displacement increases. The

Alemania Thrust carries syn-rift and basement rocks on top of post-rift and syn-orogenic sediments (Fig. 9). These sediments are folded by the Alemania Syncline in the footwall of the Alemania Thrust and are truncated by a minor thrust related to this syncline (out-of syncline). In the hanging wall of the Alemania Thrust, a 100 m basement block crops out (Fig. 9). This block of reduced dimensions is bounded to the east by an east-dipping extensional fault, which corresponds to the western border of the lower syn-rift package. However, the upper syn-rift sediments extend westwards covering the aforementioned basement block. Here, syn-rift sediments consist of breccias and conglomerates with heterometric pebbles, whereas, in the eastern Pampa Juntas, they are made up of sandstones that progressively onlap basement rocks to the east (Fig. 9).

West of the Santa Bárbara range, the north–south general trending Tres Cruces Thrust shows a sinuous geometry parallel to the Santa Bárbara Thrust and carries basement rocks on top of syn-rift sediments (Fig. 9). In the Quebrada Don Bartolo, basement rocks of the Tres Cruces Thrust hanging wall show different relationships with the syn-rift sediments. The lower Pirgua sediments are limited to the west by north–south- to NNE–SSW-trending east-dipping extensional faults, presenting basement rocks in their footwalls. The upper syn-rift sediments unconformably overlie these basement rocks and are folded by the Don Barbosa Anticline (Carrera 2009).

In the hanging wall of the Tres Cruces Thrust and next to the Santa Bárbara Thrust, the lower post-rift sediments of the Balbuena Subgroup crop out (Fig. 9), constraining the maximum thickness of the syn-rift sediments in this area as well as the maximum displacement of the Santa Bárbara Thrust (Fig. 9).

In the hanging wall of the Santa Bárbara Thrust, basement rocks core the Santa Bárbara Anticline, and syn-rift sediments unconformably overlie its eastern limb. Eastwards, a wide syncline cored by Balbuena sediments constrains the thickness of the syn-rift sediments in this area (Fig. 9). This syncline is NNE–SSW trending but, towards the north, it takes a NW–SE trend and is relayed by the Pampa Juntas Syncline. The same direction is present in this last syncline but is located to the NE. In the relay area between these two synclines, a minor anticline crops out (Fig. 9).

The presence of the Balbuena Subgroup in these two previously described thrusts permitted the establishment of the relative thickness of syn-rift sediments. The minimum thickness measured in the hanging wall of the Tres Cruces Thrust is larger than the maximum measured in the Santa Bárbara Thrust at the Quebrada Don Barbosa latitude (Fig. 9).

West of Pampa Grande, the east-directed and NE–SW-trending Pampa Grande Thrust carries syn-rift sediments on top of post-rift and syn-orogenic sediments. In the hanging wall of this thrust, the Cerro Pirgua Anticline, which is parallel to the Pampa Grande Thrust, folds syn-rift sediments (Fig. 9). In this anticline, syn-rift sediments are thicker than in the Santa Bárbara Anticline at the same latitude.

In the eastern margin of the area, the NNE–SSW-trending Sierra de Rosario Anticline is highlighted because of the thin syn-rift sequence involved. Westwards, the adjacent Alto de la Mesada Anticline involves a thicker syn-rift sequence (Fig. 9).

Interpretation. The different orientations and vergences for the observed structures in the Alemania–Pampa Juntas–Acosta Valley area are related to the inversion of a stepped extensional fault system with a change in vergence. This area corresponds to a transfer zone with respect to the differently oriented Cretaceous extensional fault system, with NNW–SSE extensional faults in the western parts and NE–SW ones on the eastern side (Figs 10 & 11). Extensional faults have controlled the polarity variations of both facies and the thickness of the syn-rift sediments. Thus, the transfer zone would have resulted in a thickening of the syn-rift sediments in two directions: eastwards in the southern area (Cerro Pirgua) and in the opposite direction (westwards) further north in the Alemania area. In addition, in the latter area, sediments coarsen westwards as they thicken.

The geometries observed in the NW part of the Alemania–Pampa Juntas–Acosta Valley area suggest that the northern tip of the Santa Bárbara Thrust has reactivated a previous high dip angle extensional fault (Fig. 9).

Facies distribution of the syn-rift sediments, as well as their geometrical relationships around the basement block of the hanging wall of the Alemania Thrust, together with the eastwards onlap of the fine syn-rift sediments in the Pampa Juntas area, suggest that the Alemania Thrust results from the inversion of a half-graben. The main extensional fault dips to the east and the aforementioned basement block corresponds to a shortcut structure (Fig. 9).

In the Quebrada Don Bartolo, the geometrical relationships between syn-rift and basement rocks in the hanging wall of the Tres Cruces Thrust suggest the inversion of a half-graben, where the basement blocks of the east-dipping extensional fault footwalls correspond to shortcuts. This inversion would have developed the Don Barbosa Anticline. At this latitude, the aforementioned inversion,

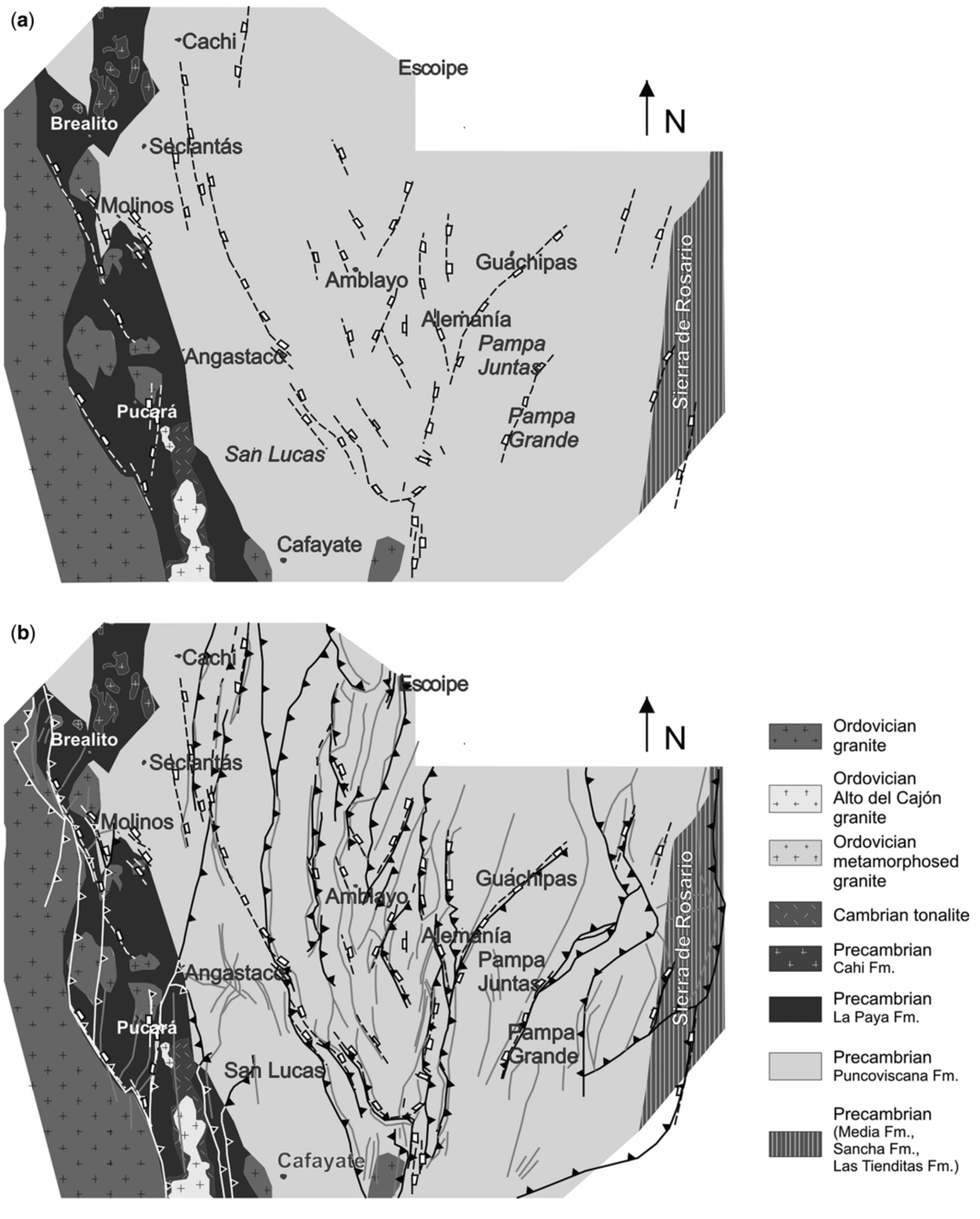


Fig. 10. (**a**) Schematic palaeogeographical map of basement rocks in the southern Cordillera Oriental. Note that the area is dominated mainly by low-grade metamorphic rocks, with granite intrusions towards the west. Cretaceous extensional faults have also been represented. (**b**) Superposition of (a) with a map of the Andean structures developed in the southern Cordillera Oriental. Grey lines depict folds and black lines thrusts.

together with syn-rift thickness variations at both sides of the Santa Bárbara Thrust, suggest that this thrust represents a bypass structure. The change on structural style of this thrust must be emphasized as it corresponds to a bypass structure in the south and an inversion structure in the north.

At this same latitude, syn-rift thickness variations between the Cerro Pirgua Anticline and the

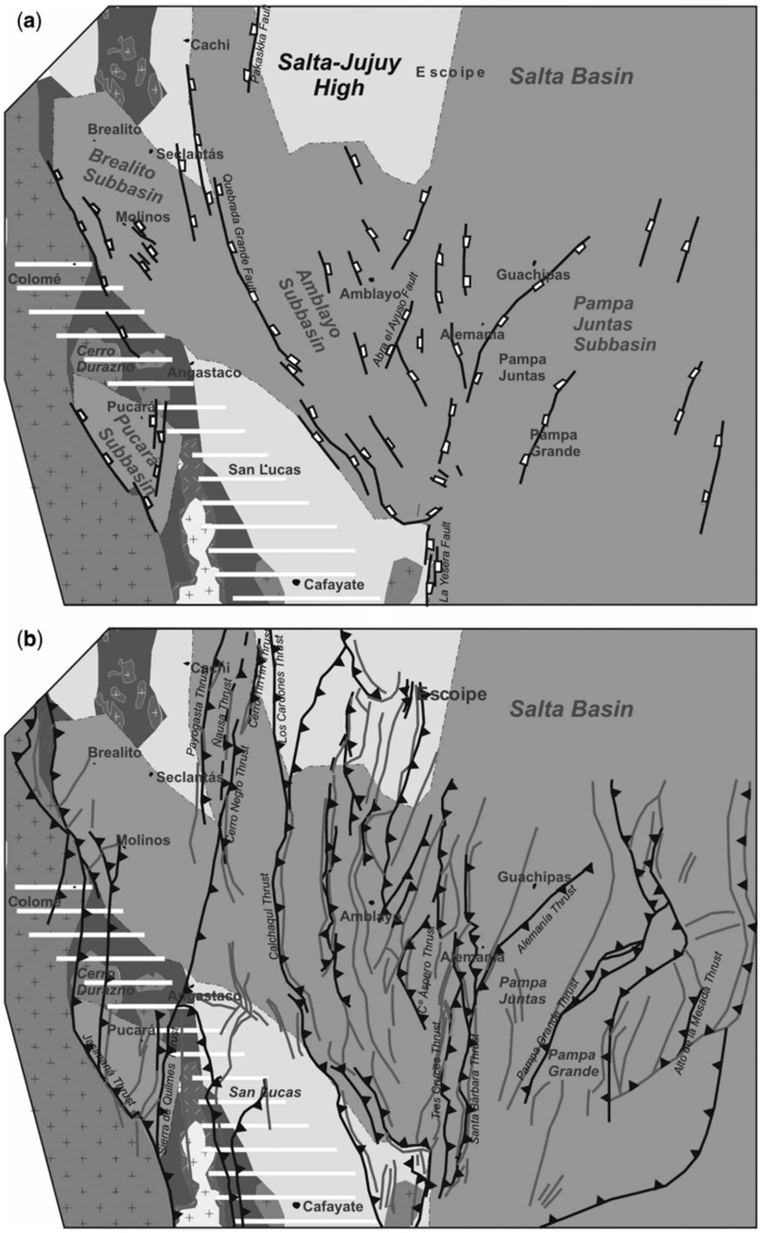


Fig. 11. (**a**) Schematic palaeogeographical map of syn-rift sediments on top of the basement rocks map of Figure 10a. Cretaceous extensional faults have also been represented. Note that the study area comprises the western margin of the Salta Basin, as well as the Salta–Jujuy High. In this figure, an area has also been highlighted between the Pucará Sub-basin and the Amblayo Sub-basin, which was uplifted during Cretaceous times, as measured by Sobel & Strecker (2003) and Deeken *et al.* (2006) from apatite fission-track analyses. (**b**) Superposition of the map of syn-rift sediments with a map of the Andean structures developed in the southern Cordillera Oriental. Grey lines depict folds and black lines thrusts.

Santa Bárbara Anticline suggest that the depocentre of this sub-basin was located to the east, as well as the fault that controlled the accommodation space for these sediments. The Pampa Grande Thrust probably inverted this previous NNE–SSW-trending extensional fault.

Syn-rift thickness changes between the Alto de la Mesada Anticline and the Sierra de Rosario

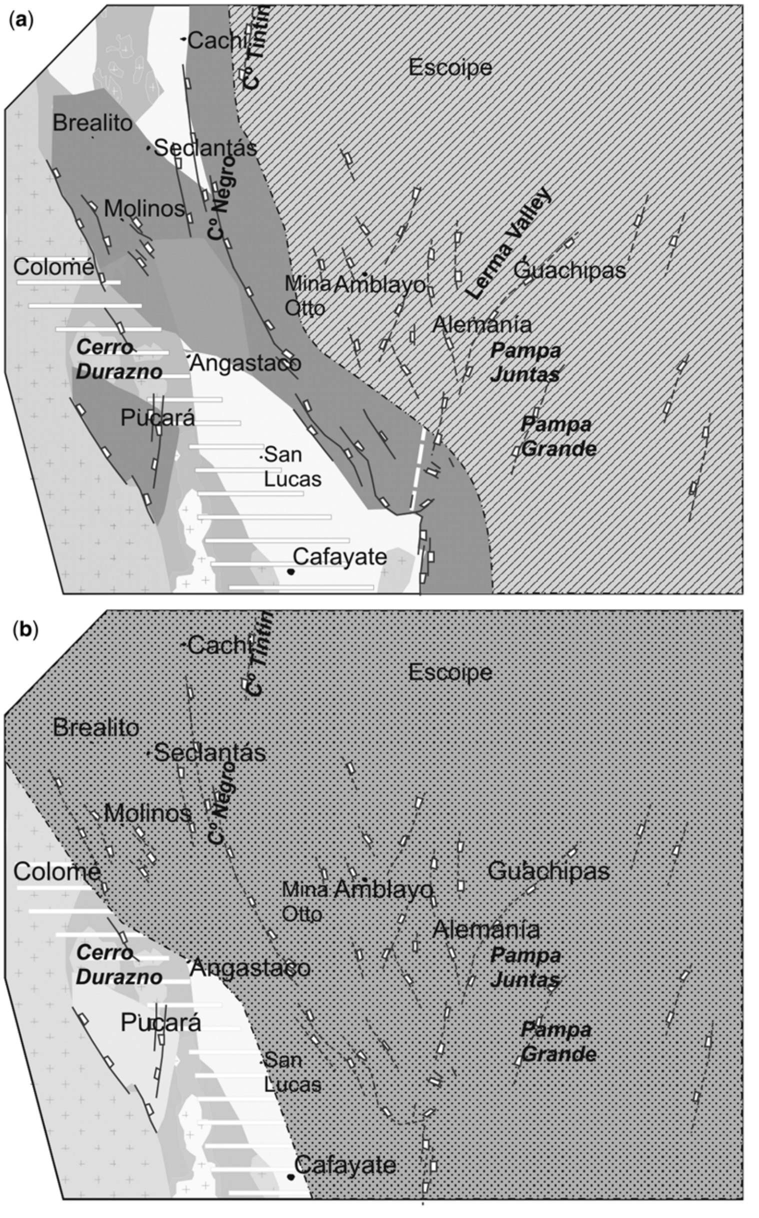
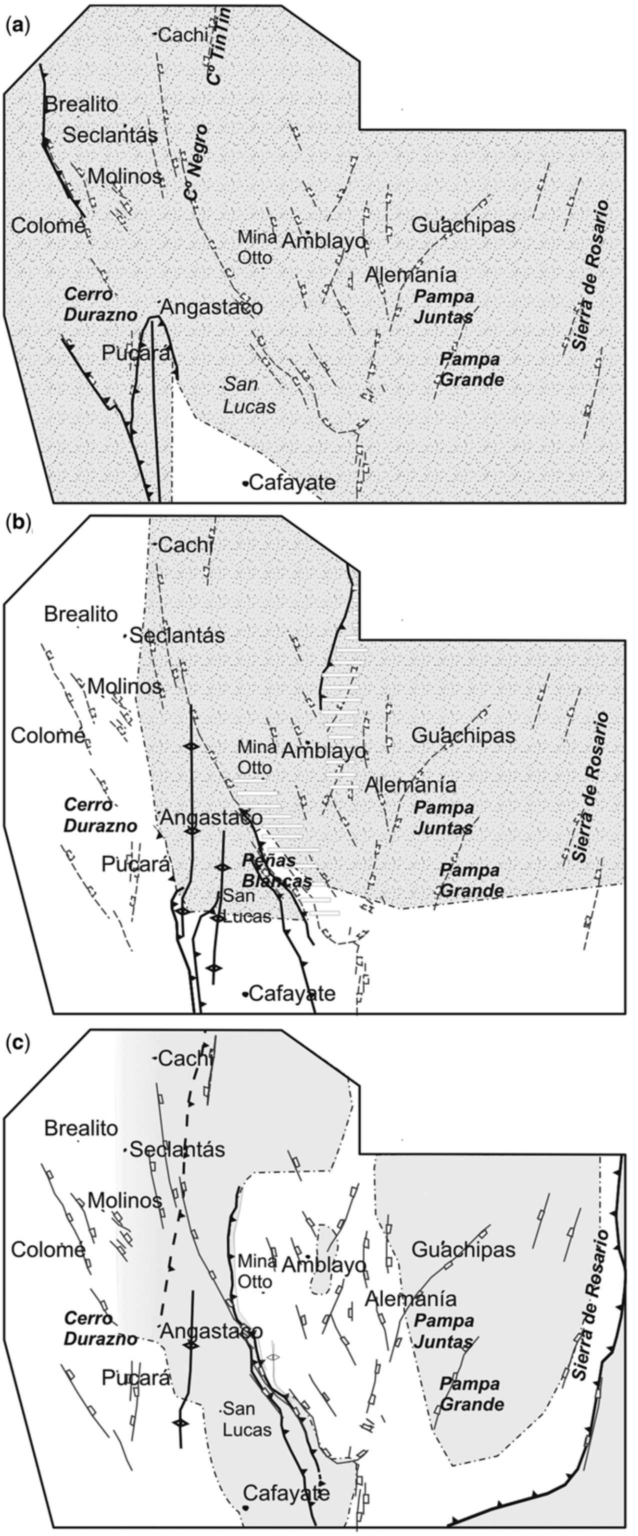


Fig. 12. (**a**) Schematic palaeogeographical map of the post-rift sediments of the Balbuena Subgroup. Note that the western margin of the Balbuena Subgroup Basin is parallel to the margin between non-intruded basement rocks to the east and the intruded basement rocks to the west. Moreover, Balbuena Subgroup sediments cover the Salta–Jujuy High to the north. Cretaceous extensional faults developed in the southern Cordillera Oriental have been represented. (**b**) Schematic palaeogeographical map of the post-rift sediments of the Santa Bárbara Subgroup. Note that the western margin of this subgroup overlaps the Balbuena western margin, reaching the eastern limb of the Cretaceous uplifted area, located between the Pucará Sub-basin and the Amblayo Sub-basin. Cretaceous extensional faults developed in the southern Cordillera Oriental are also represented.

Anticline suggest the inversion of a half-graben, which developed the Alto de la Mesada Anticline. The Alto de la Mesada Thrust would have inverted the west-dipping extensional fault, and the Sierra de Rosario would represent a shortcut structure (Fig. 9).


(a)
Cachi
Cº Tin Tin
Brealito
Seclantás
Molinos
Cº Negro
Colomé
Guachipas
Mina Otto
Amblayo
Alemanía
Sierra de Rosario
Cerro Durazno
Angastaco
Pampa Juntas
Pucará
Pampa Grande
San Lucas
Cafayate
(b)
Cachi
Brealito
Seclantás
Molinos
Colomé
Mina Otto
Amblayo
Guachipas
Alemanía
Sierra de Rosario
Cerro Durazno
Angastaco
Pampa Juntas
Pucará
Peñas Blancas
Pampa Grande
San Lucas
Cafayate
(c)
Cachi
Brealito
Seclantás
Molinos
Colomé
Mina Otto
Amblayo
Guachipas
Alemanía
Cerro Durazno
Angastaco
Pampa Juntas
Sierra de Rosario
Pucará
Pampa Grande
San Lucas
Cafayate

Basement anisotropies

As previously mentioned, the basement of the southern Cordillera Oriental is mainly formed by Precambrian–Lower Cambrian low-grade metamorphic rocks, with an increase in the metamorphic grade towards the west (Fig. 10). In the same direction, the presence of plutonic bodies increases, being predominant in the westernmost part of the study area (Fig. 10). The general NW–SE trend of the boundary between intruded and non-intruded basement rocks must be emphasized.

Little is known about the internal structure of the basement in the study area. Even so, some local features have been observed: north–south-trending folds with the steeply east-dipping axial-plane fold rocks of the Puncoviscana Formation in the Quebrada Don Bartolo; the basement rocks involved in the Alemania Anticline present beds dipping to the NE; and basement rocks of the La Loma Negra (south of the southern Cordillera Oriental) show steeply dipping west-verging foliations. All of these features are consistent with the Late Ordovician west-verging Ocloyic Orogeny (Aceñolaza & Toselli 1976), which developed west-verging folds and thrusts with an axial-plane cleavage steeply dipping to the east (Mon & Hongn 1991).

The eastern boundary of the Ocloyic thrust and fold belt trends north–south, and is located near the Las Conchas River in the middle of the study area (Mon 1994) (Fig. 2). Eastwards of this boundary, the predominant basement anisotropy corresponds to NE–SW-trending structures, such as the foliations and different scale folds, with a change in plunge angle described around the Sierra de Rosario by Nesossi (1947).

Finally, around Molinos and during the Early Palaeozoic, conjugated predominantly north–south- and NW–SE-trending shear zones developed, affecting the metamorphic basement rocks (Hongn & Becchio 1999; Becchio *et al.* 2008).

Salta Basin

Syn-rift

The Pirgua Subgroup occupies a wide area in the eastern part of the southern Cordillera Oriental, whereas, in the western part, it shows isolated outcrops or it is absent (Figs 2 & 11). Moreover, as commented for the hanging wall of the Tintin Thrust, the study area comprises the southern edge of the Salta–Jujuy High where syn-rift sediments are absent (Figs 6 & 11).

The observed or inferred Cretaceous extensional faults of the southern Cordillera Oriental, described in this and other papers (Carrera *et al.* 2006; Carrera & Muñoz 2008), show a wide range of orientations (Fig. 11). In the western parts, the main extensional faults trend NW–SE and are east dipping, although north–south-trending and west-dipping extensional faults are locally present (Fig. 5) (Carrera & Muñoz 2008). In the north-central area, a change in the vergence of the structures is observed. The main extensional faults trend NNW–SSE and are east dipping in the west, whereas, in the east, those which are NNE–SSW trending and west dipping predominate (Figs 5 & 11) (Carrera *et al.* 2006). Eastwards, in the Pampa Juntas area, the main extensional faults trend NNW–SSE and dip to the east in the west and to the west in the east (Figs 9 & 11). In the south-central area, there is a change in the orientation between NW–SE- and north–south-trending faults, whereby both are east dipping and, in between, a west–east-trending relay fault system developed (Fig. 11) (Carrera *et al.* 2006).

From the distribution and geometry of the extensional faults, and the thickness and facies variations of the syn-rift sediments, it may be inferred that in the southern Cordillera Oriental the Salta Basin was initially fragmented into four sub-basins: the Pucará, Brealito, Amblayo and Pampa Juntas sub-basins (Fig. 11).

The western rift margin of the Salta Basin has a NNW–SSE orientation and corresponds with the left-lateral stepped extensional faults of the Calchaquí Valley. The footwall of this fault system experienced an uplift and exhumation during the extension, as evidenced by the Cretaceous ages yielded by fission-track data from apatites in the basement rocks along a NNW–SSE band through Colomé, Cerro Durazno and Cumbres Calchaquies (Fig. 11) (Sobel & Strecker 2003; Deeken *et al.* 2006). This Cretaceous uplift was responsible for the disconnection of the Pucará Sub-basin from the other sub-basins.

A subcrop map of the basement rocks with the superimposition of the Mesozoic extensional faults highlights the location and parallelism of the

Fig. 13. (**a**) Schematic palaeogeographical map of the syn-orogenic sediments of the lower Metán Subgroup. Note that they were deposited in a single foreland basin covering all of the Cretaceous sub-basins. Active structures are represented. (**b**) Schematic palaeogeographical map of the upper Metán Subgroup. Active structures are represented. Note that deformation progressed towards the east compared to (a). (**c**) Schematic palaeogeographical map of the upper syn-orogenic sediments of the Jujuy Subgroup and the Quaternary. Active structures are represented. Note that these sediments are concentrated along the main thrusts that invert the main extensional fault system. Moreover, deformation progressed eastwards faster than before.

western rift margin of the Salta Basin with respect to the boundary between the crystalline basement and its sedimentary counterpart (Fig. 10). Moreover, west of the main extensional margin, the master extensional faults of the Pucará and the Brealito sub-basins are also NW–SE trending, and are located around the boundary between granites and metamorphic rocks with minor intruded plutonic rocks (Figs 10 & 11).

Post-rift

The western margin of the Balbuena Subgroup basin is located some kilometres inside the Amblayo Sub-basin and runs parallel to the reconstructed rift margin; thus, reinforcing the interpretation of its position and orientation (Fig. 12a). The thickness of the Balbuena Subgroup increases eastwards (Lerma Valley) and northwards, where it overlies the basement of the Salta–Jujuy High (i.e. Escoipe and Cerro Tintin areas: Figs 4 & 12a). As previously commented, the western margin of its depositional basin is located some kilometres inside the Amblayo Sub-basin, parallel to major extensional faults (Fig. 12a).

The Santa Bárbara Subgroup is more expansive than the Balbuena Subgroup. Their sediments extend westwards beyond the main extensional fault system, unconformably overlying both the syn-rift and the basement rocks. Its depositional basin defines a NW-trending basin margin (Fig. 12b), constrained westwards by the Cretaceous uplifted area in the footwall of the main extensional basin (Sobel & Strecker 2003; Deeken *et al.* 2006).

Syn-orogenic

The lower syn-orogenic sediments, belonging to the Quebrada de los Colorados Formation and the Metán Subgroup, were deposited into a mostly continuous foreland basin (Fig. 13a, b) (Carrera & Muñoz 2008; Carrera 2009). Deformation at this time progressed at a low rate from the western margin of the southern Cordillera Oriental up to the Calchaquí Valley area, west of the Amblayo Sub-basin margin (from 40 to 12 Ma). At this time, Andean deformation was located in the western margin of this sub-basin and displaced faster eastwards, reaching the eastern margin of the southern Cordillera Oriental at 10 Ma (Carrera & Muñoz 2008; Carrera 2009). This is corroborated by the unconformity and the onlap found by Cristallini *et al.* (1997) in seismic profiles at the base of the Jujuy Subgroup in the western Metán Basin, next to the eastern front of the southern Cordillera Oriental. Thus, the Jujuy Subgroup was accumulated in a fragmented foreland, mainly in specific areas: the Calchaquí Valley, the Lerma Valley and east of the Sierra de Rosario (Fig. 13c). It is interesting to emphasize that these areas coincide with both the margins of the main extensional fault system of the area and the areas where the Quaternary rocks were accumulated.

Discussion

The peculiar thick-skinned structural style of the southern Cordillera Oriental is characterized by: (i) basement involved, high-angle thrusts and related folds; (ii) relatively thin thrust sheets when compared with the thickness of the basement and sedimentary pile involved; (iii) a persistent back-thrust system coeval with the forward migration of the Andean deformation; (iv) variable rates of deformation forward advance and mode of thrust sequences through time; and (v) great variety of structural orientations developed synchronously. All of these documented features, together with the location, geometry and facies distribution of the basins involved in the deformation, the basement́s structural and lithological features and the available thermochronological data, allow us to decipher and discuss the role of the structural inheritance in the successive tectonic events that have resulted in the present geometry and structural style of the Cordillera Oriental.

The tectonic inversion of the Cretaceous extensional system can explain most of the aforementioned features, as has been largely described in the southern Cordillera Oriental or surrounding areas (Grier *et al.* 1991; Kley & Monaldi 2002; Kley *et al.* 2005; Carrera *et al.* 2006; Carrera & Muñoz 2008; Iaffa *et al.* 2011). Structures that resulted from a positive inversion tectonic event have also been described in this paper, supporting the important role played by the inversion of Cretaceous extensional structures in the development of the Andean contractional structures. However, not all of the structural features departing from the expected geometries for the Andean thrust and fold belt can be simply explained by the aforementioned inversion tectonics, suggesting the role played by the anisotropies of the basement on the Andean structures of the area.

The basement structural grain has already controlled the location and geometry of the Cretaceous extensional faults. The distribution of the main lithologies determined the position of the rift margin and the main basin bounding extensional faults (Figs 5 & 11). In addition, the basement internal structural fabric would have controlled the orientation of the extensional fault system to the extent that could even explain the intricate geometry of the Salta Basin faults. Thus, the NW–SE orientation of the extensional faults at the western rift margin are not only parallel to the boundary between the crystalline basement with metamorphic rocks intruded by granites and the sediments of the Puncoviscana Formation but also to the NW–SE shear zones that deform the basement rocks (Hongn & Becchio 1999; Becchio *et al.* 2008). In the eastern southern Cordillera Oriental, the predominant NE–SW extensional faults parallelize the NE–SW structural fabric of the basement (Nesossi 1947).

At more detailed scales, the control of the basement anisotropies in the extensional faults has also been observed. In the Quebrada Don Bartolo, in the centre of the studied area, north–south to NNE–SSW metric-scale extensional faults are parallel to the steeply east-dipping basement fabric (axial surfaces and fold limbs of tight to isoclinal folds).

One of the most striking structural features of the studied area is the north–south-trending closely spaced thrust system of backthrusts in the central part (Figs 2 & 4). This system is characterized by high-angle thrusts with very tight fault-related folds with overturned forelimbs. These thrusts, however, are not the result of the reactivation of single Mesozoic extensional faults all along their trace. Instead, they partially reactivate different extensional faults and connect them along the strike (Figs 10 & 11). This central north–south thrust system coincides with the eastern boundary of the Ocloyic orogenic system, which is characterized by west-verging structures (Mon 1994). The existence of this tectonic boundary and its related structures, but mostly the presence of a steeply east-dipping fabric, would have favoured the development of the north–south system of backthrusts. Also, the reactivation of such fabric by flexural slip and flexural flow would explain the internal deformation of the basement and the development of the anomalously tight fault-related folds affecting the Mesozoic–Cenozoic succession overlaying the basement that characterizes this thrust system. Moreover, the reactivation of the east-dipping basement fabric would also explain the non-reactivation of the Mesozoic extensional faults and their folding regardless of the fact that they show *a priori* favourable orientation (Figs 5 & 7).

Most of the shortening measured on the regional cross-section has been mostly concentrated in both the north–south central thrust system and the inverted margins of the Cretaceous basin. These areas would be connected by an intracrustal detachment that would have been inherited from the extensional detachment connecting at least the Amblayo Sub-basin with the Pampa Juntas Sub-basin. Reactivation of such a detachment would be suggested by the fast propagation of the deformation (from 12 to 10 Ma), once the thrust front would had reached the western boundary of the Amblayo Sub-basin.

Conclusions

- Inversion tectonics play a significant role in the structural evolution of the southern Cordillera Oriental. Both inversion of Cretaceous extensional faults and the reactivation of basement anisotropies occurred during the Andean deformation.
- In the western southern Cordillera Oriental, most of the east-dipping extensional faults (the main ones) develop inversion structures during the Andean deformation; however, west-dipping extensional faults (the antithetic ones) are preserved and folded in the footwall of west-directed backthrusts. Both of these kinds of Andean structures reactivate basement anisotropies. Moreover, the Cretaceous extensional system is also constrained by the basement, as the main extensional faults of the Salta Rift Basin in this area are east-dipping, probably reactivating basement anisotropies. Conversely, the west-dipping antithetic extensional faults were newly created to accommodate the deformation of the main extensional faults.
- The Salta–Jujuy High was part of the Salta Rift system and developed on top of a basal detachment, which was reactivated during the Andean deformation.
- The reactivation of previous anisotropies not only influenced the variations in orientation and vergence, but also the temporal distribution of deformation, as shown by the localization of the deformation along the main Cretaceous extensional fault system from 10 Ma until Recent.
- Basement anisotropies controlled the shape of the Salta Basin at this latitude, resulting in an asymmetric rift at the crustal scale with a main fault system dominated by east-dipping faults.
- Lithology variations between basement rocks controlled the main boundaries of the Salta Rift in the southern Cordillera Oriental, both the main extensional fault system (Amblayo and Pampa Juntas sub-basins) and the minor sub-basins (Pucará and Brealito sub-basins).

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