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The Palaeozoic basement of the Andean Frontal Cordillera at 34º S (Cordón del Carrizalito, Mendoza Province, Argentina): Geotectonic implications

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Abstract

The Cordón del Carrizalito is located in the southern sector of the Andean Frontal Cordillera. In this area, the Andean basement is composed of meta-sedimentary rocks (Las Lagunitas Formation) of Ordovician age. In addition, no- or very low grade metamorphism and less deformed rocks also occur in the study area. We call these rocks Selerpe series, whose characteristics are comparable to other series, late Carboniferous in age, described in nearby areas. The Las Lagunitas Formation is affected by west-verging folds, developed under low-grade metamorphic conditions. These structures can be attributed to the Chanic orogeny (Late Devonian – early Carboniferous). The Selerpe series and Las Lagunitas Formation are deformed by east-verging thrusts and folds developed in narrow bands and generated in the absence or under very low metamorphic conditions. These structures always deform the Chanic structures, and are attributed to the Gondwanan deformation (San Rafael orogeny, late Carboniferous – Permian in age). The Chanic structures of the study area can be placed in the western branch and in the hinterland of the Chanic orogen, which was developed as a result of the accretion of the Chilenia terrane at the west Gondwana margin during Late Devonian and early Carboniferous. The eastern branch of this orogen is located in the Andean Precordillera. The Permo-Triassic cover, deformed by the Andean orogenic cycle (Mesozoic – Cenozoic), rests unconformably on the Palaeozoic basement rocks.

Keywords: Palaeozoic basement, Chanic orogeny, Gondwanan deformation, Andes, Argentina

Resumen

En el Cordón del Carrizalito, situado en el sector meridional de la Cordillera Frontal de los Andes, afloran metasedimentos ordovícicos pertenecientes a la Formación Las Lagunitas y otro conjunto de rocas menos deformadas, en ausencia de metamorfismo o con metamorfismo de muy bajo grado, que hemos denominado serie de Selerpe. Esta última es litoestratigráficamente comparable a series del Carbonífero superior descritas en áreas próximas. La Formación Las Lagunitas está afectada por pliegues apretados, vergentes al oeste y desarrollados bajo condiciones de metamorfismo de bajo grado. Estas estructuras pueden ser atribuidas a la orogenia Chánica (Devónico Superior - Carbonífero inferior). La deformación Gondwánica, atribuida a la orogenia San Rafael, (Carbonífero superior – Pérmico), afecta tanto a la serie de Selerpe como a la Formación Las Lagunitas y se caracteriza por cabalgamientos y pliegues vergentes al este y generados en ausencia de metamorfismo o bajo condiciones metamórficas de muy grado bajo. Las estructuras chánicas de la zona estudiada se encuentran en las zonas internas de la rama occidental del orógeno del mismo nombre. Estas estructuras se desarrollaron como resultado de la acreción del terreno de Chilenia al margen occidental del antiguo continente de Gondwana durante el Devónico Superior – Carbonífero inferior. La rama oriental del orógeno Chánico se sitúa en la Precordillera andina. La cobertera permo-triásica, deformada durante el Mesozoico y Cenozoico por el ciclo orogénico Andino, se apoya discordantemente sobre las rocas del basamento paleozoico.

Palabras clave: Basamento Paleozoico, orógeno Chánico, deformación Gondwánica, Andes, Argentina

1. Introduction

The Cordón del Carrizalito (Carrizalito range) is located at 34º S latitude, in the Mendoza province (Argentina), forming the southern part of the Frontal Cordillera of the Andes (Groeber, 1938). Since the early work in this sector of the Andes (Ramos, 1988) it is accepted that the Palaeozoic basement rocks were part of two continents, Chilenia terrane and

Gondwana, located to the west and east respectively. These continents, separated by a narrow ocean, collided during the Chanic orogeny in Late Devonian to early Carboniferous times. The subsequent subduction of the Pacific plate in the western margin of ancient Chilenia, resulted in the Gondwanan deformation during the late Carboniferous – Permian. The Chilenia terrane is currently represented by the rocks of the Andean Frontal Cordillera, while the Gondwana continent is formed by the rocks of the Andean Precordillera (Fig. 1).

The Andean Frontal Cordillera contains a Palaeozoic basement that consists of sedimentary, metamorphic and igneous rocks, strongly deformed during the Chanic and San Rafael (Gondwanan deformation) orogenies and intruded by Upper Palaeozoic granitoids (Ramos, 1988; Heredia *et al*., 2012). The age of the rocks of this basement range from the Neoproterozoic (Ediacaran) (de Azarevich *et al*., 2009) to Lower Permian (Polanski, 1970; Heredia *et al*., 2002; Folguera *et al*., 2003; Busquets *et al*., 2005).

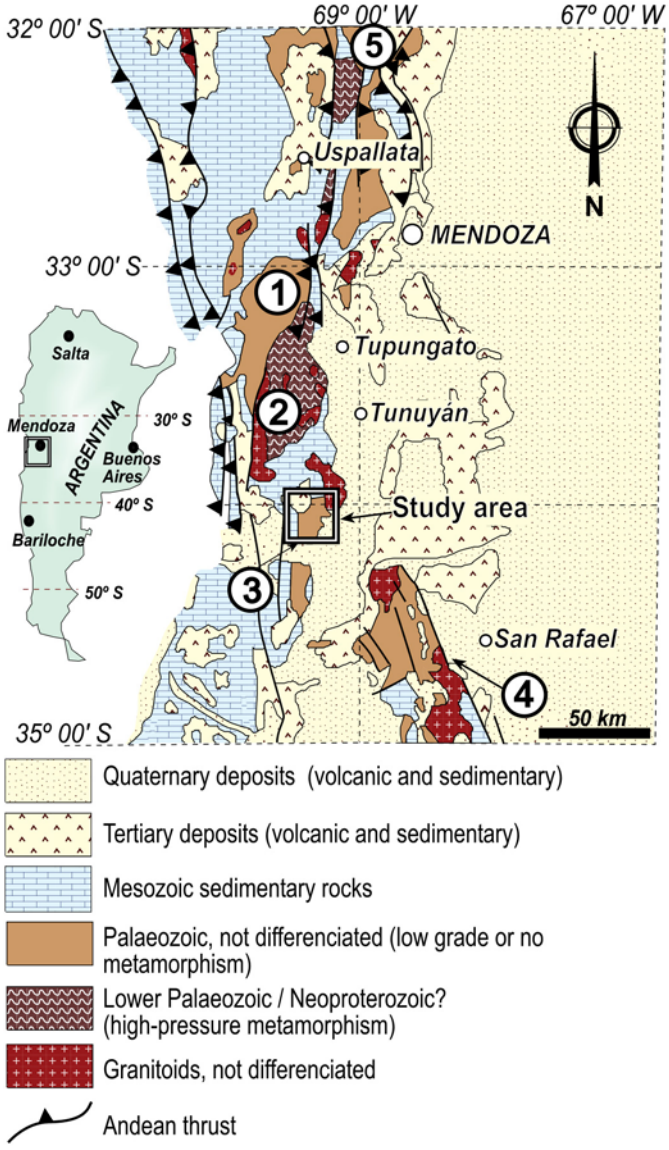

Fig. 1.- Geological map of the Andean Frontal Cordillera between 32º - 35º south latitude. Black double frame shows location of the study area. (1) Cordón del Plata, (2) Cordón del Portillo, (3) Cordón del Carrizalito, (4) San Rafael Block, (5) Precordillera.

In the Cordon del Carrizalito, rocks of this basement have been deformed by structures that can be assigned to the three orogenic episodes present in the region: Chanic, Gondwanan and Andean. The results of our study of these rocks and the structure in two sections, reported herein, permit to place the study area in the geological context of the Andean Frontal Cordillera. Permo-Triassic and Cenozoic sedimentary, volcanic and volcaniclastic rocks unconformably overlie the Palaeozoic basement (Fig. 2). This Andean cover was deformed and intruded by granitoids during the Andean orogenic cycle.

2. Lithology

2.1. Las Lagunitas Formation

In the southern part of the Cordón del Carrizalito the basement is represented by low-grade metamorphic rocks, which were assigned to the Neoproterozoic. This also accounts to the pre-Andean basement outcropping to the north, in the Portillo and Plata ranges (Groeber, 1947). Volkheimer (1978) named the metamorphic rocks of the Cordón del Carrizalito as Las Lagunitas Formation. In the study area, the Las Lagunitas Formation has been described by Tickyj *et al*. (2009b). The base and top of this Formation are not exposed, although a 5,000 m minimum thickness can be deduced from the geological section (Fig. 3). It consists of sandstones, dark quartzites and black slates alternating on a decimetric to metric scale. Sandstones show abundant sedimentary structures as cross-bedding, ripple marks, flute cast and load casts (Fig. 5c). On the basis of these structures the rocks were interpreted as of turbiditic origin (Sruoga e*t al*., 2005).

This formation has been compared with other ones included in the Bloque San Rafael (SE of the study area, Fig. 1), and assigned to the Devonian (Volkheimer, 1978; Caminos, 1979). However, graptolites of the biozone *Climacograptus bicornis* have been recently found in the slates (location in Fig. 2). They permit to date these rocks as Upper Ordovician (Tickyj *et al*., 2009b).

2.2. Selerpe series

During our field work it turned out that parts of the rocks previously included in the Las Lagunitas Formation show different facies and have not been affected by appreciable metamorphism or intense deformation. Therefore, they must belong to a different and younger formation, that we named Selerpe series. It crop out in the southeast corner of the Cordón del Carrizalito and is well exposed in the eastern part of the Quebrada de Cortaderas (Figs. 2, 3). In this section the basal part of the Selerpe series is represented by an approximately 90 m thick quartz-arenite body; the rest is composed

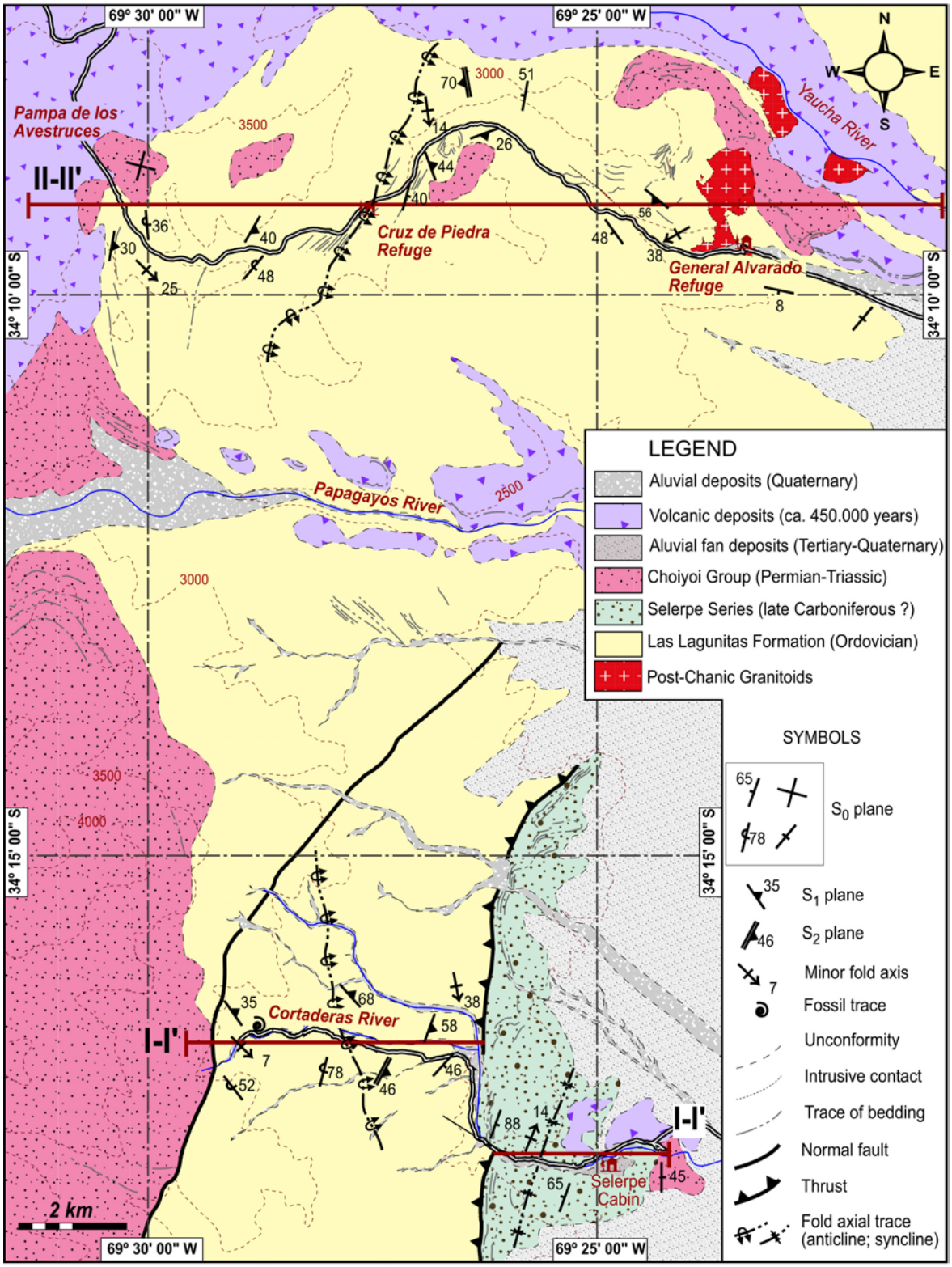

Fig. 2.- Geological map of the study area in the southern part of the Andean Frontal Cordillera (for location see Fig. 1). I-I' Line of geological cross-section of the Fig. 3 (Cortaderas river). II-II' Line of geological cross-section shown in Fig. 4 (Cruz de Piedra river).

of alternating black shales, sandstones and some conglomerates and micro-conglomerates, with cross-bedding, flute cast and load cast structures. These rocks were deformed under no- or very low metamorphic conditions. Deformation led to the development of an incipient cleavage in the shales.

The age of these rocks is unknown. North of the study area, however, some formations with a late Carboniferous age have been described resting unconformably over metamorphic rocks. They were mentioned as El Plata Formation, in the El Plata and Portillo ranges (Caminos, 1965; Caminos,

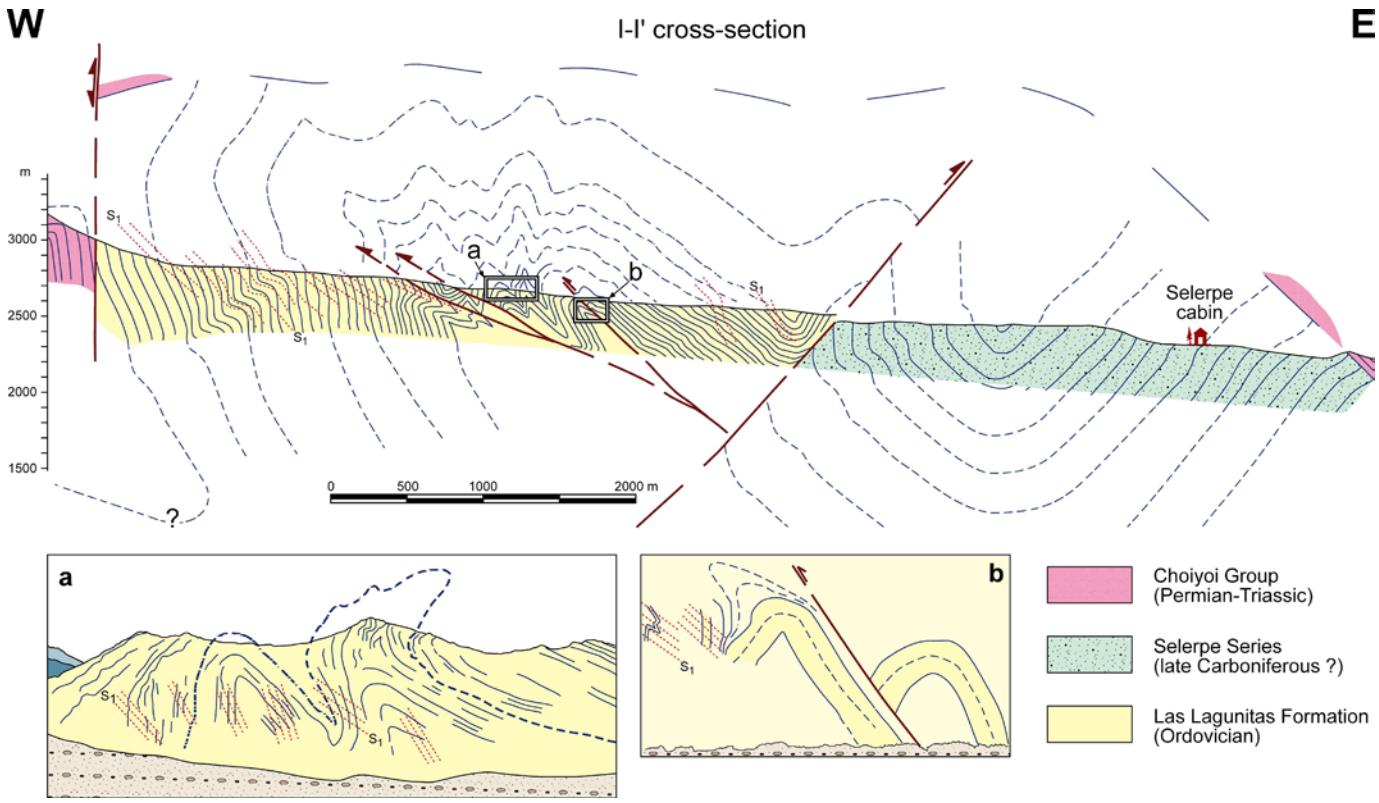

Fig. 3.- Geological cross-section of the Cortaderas river (for location, see Fig. 2). (a) Detail of the western part of the hinge zones of the Chanic anticline; this schematic picture corresponds to photograph A of Fig. 5. (b) Detail of the eastern part of the hinge zones of the same anticline; this schematic picture correspond to the photograph B of the figure 5.

1979) and, even more to the north, in the 30º S latitude, as Cerro Agua Negra Formation (Polanski, 1970). Based on its stratigraphic features and structural position, the Selerpe series can be correlated with these Carboniferous formations.

2.3. Choiyoi Group

The Choiyoi Group rests unconformable and sub-horizontally over the Palaeozoic basement. It consists of alternating acid and intermediate volcanic and volcaniclastic rocks with some associated plutonic and sub-volcanic bodies. The age of these rocks range from Permian to Triassic (Groeber, 1947; Rolleri and Criado, 1969; Cortés *et al*., 1997).

2.4. Igneous rocks

The Las Lagunitas Formation is intruded by a set of granites, granodiorites and tonalites with ages ranging from Silurian to Lower Triassic (Caminos *et al*., 1979). In the study area, the older Pampa de los Avestruces granite is Lower Devonian in age and shows evidences of compressive deformation during emplacement (Tickyj *et al*., 2009a). Further

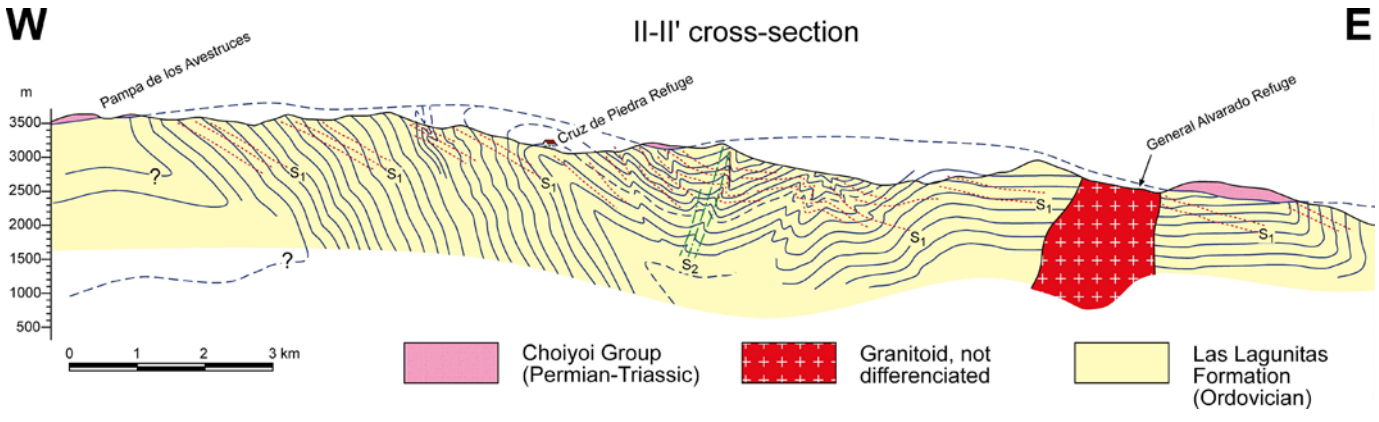

Fig. 4.- Geological cross-section of the Cruz de Piedra river. Location is shown Fig. 2.

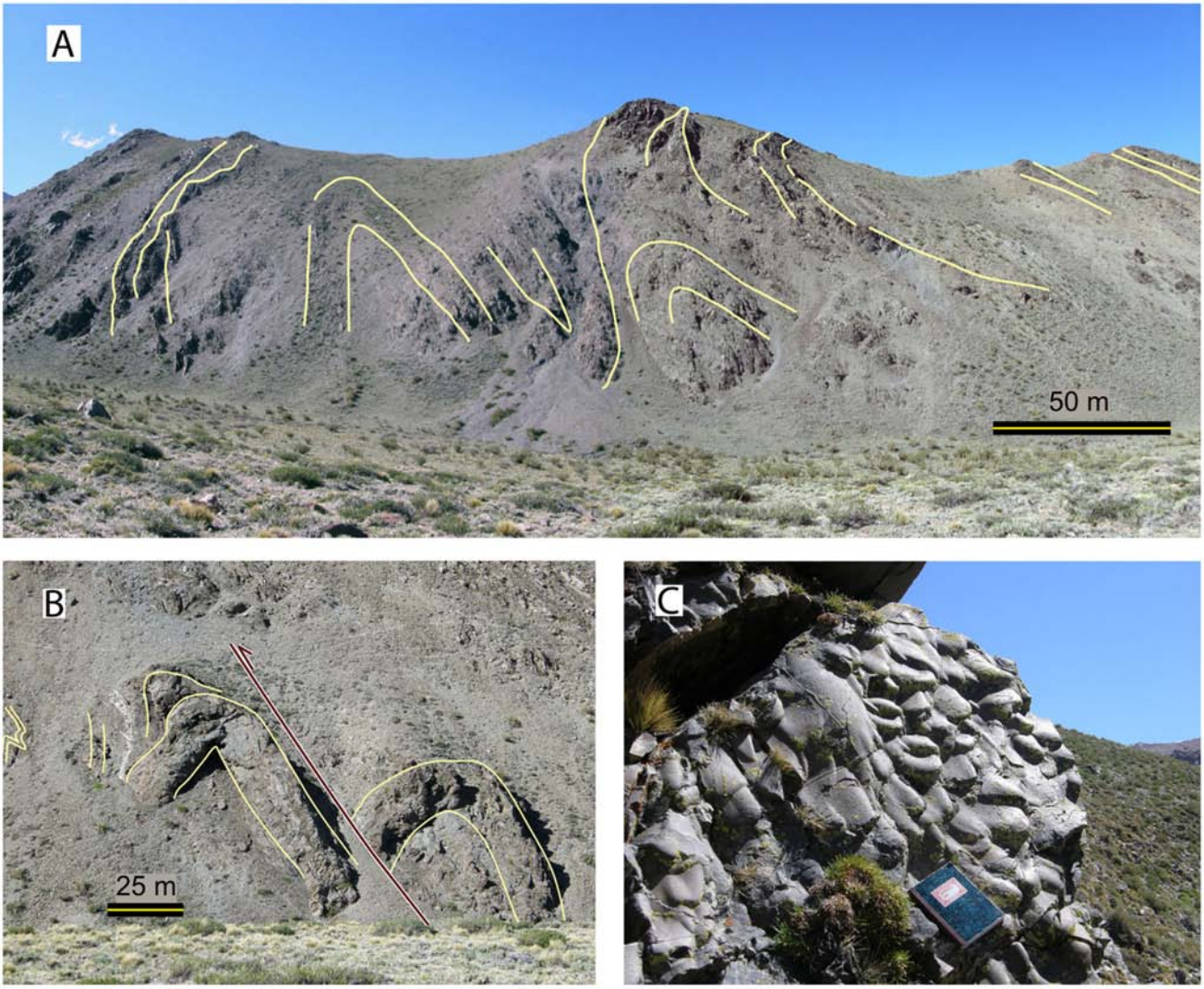

Fig. 5.- Photographs from the Cortaderas river zone. (A) Western part of the hinge zones of the Chanic anticline (view towards the north); traces of bedding planes are indicated by yellow lines; a schematic picture of this photograph is shown in Fig. 3a. (B) Eastern part of the hinge zones of the Chanic anticline (view towards the north); traces of bedding planes are indicated by yellow lines, trace of reverse fault is marked by red line; a schematic picture of this photograph is shown in Fig. 3b. (C) Flute cast and load cast in quartzites of the Las Lagunitas Formation.

to the south, the Carrizalito tonalite is dated as early Carboniferous (341±17, K-Ar in Biotite) (Dessanti and Caminos, 1967; Linares, 1977). Both bodies contain abundant mafic micro-granular enclaves constituted by plagioclase, quartz, K-feldspar and biotite, and show the characteristic geochemical signature of a calc-alkaline arc (Tickyj, 2011). They are affected by a cataclastic foliation. In the surroundings of the General Alvarado refuge (Fig. 2), an additional number of outcrops of granite and biotite monzogranites, attributed to the Choyoi Group have been described (Tickyj *et al*., 2009a). These igneous bodies led to a contact metamorphism in the country rocks with the growth of biotite, cordierite and andalusite.

3. Structure

In the study area, west-verging folds with associated cleavage (S_1) can be observed. They are deformed by east-verging folds and thrusts developed under no appreciable to very low metamorphic conditions. Up-right open folds and faults also exist, affecting the unconformably overlying Choiyoi Group. By using cross-cutting relationships, age of the rocks and metamorphic conditions during deformation, these structures can be assigned to three deformation episodes, belonging to the Chanic, Gondwanan and Andean orogenic events.

3.1. Chanic structures

Chanic structures are only developed on the Las Lagunitas Formation. They are west-verging tight folds on all scales. In the Quebrada de Cortaderas, rocks are folded by a kilometric scale anticline with an overturned limb more than 2 km thick dipping 60º to the east and a normal limb dipping 40º in the same sense way (Fig. 3). Minor folds on a decametric scale in the hinge zone occasionally are affected by west-directed thrusts (Fig. 5a, 5b). Another big west- verging anticline is ex-

posed in the Quebrada de la Cruz de Piedra, with an overturned limb more than 5,000 m thick dipping 65º to the west and a sub-horizontal normal limb (Fig. 4). Associated with these folds a slaty cleavage in the slates (S_1) and a rough cleavage in the quartzites are developed (Figs. 6a, b). The trend of the fold axes varies from NW-SE in the southern part of the Cordón del Carrizalito to NE-SW in the northern part of the study area (Fig. 2). The axes usually show a gentle plunge towards the NW, and are steeply plunging when affected by later structures (Figs. 3, 5). The S_1 cleavage is well developed in slates as a slaty cleavage mainly defined by the preferred orientation of phyllosilicates and quartz, (Fig. 7c, d). In quartzite layers it appears as a continuous cleavage (Fig. 7a).

3.2. Gondwanan structures (San Rafael orogeny)

The most representative Gondwanan structures are located in the Quebrada de Cortaderas, where the Selerpe series was folded by an up-right syncline. No foliation is associated with this fold. Only a rough cleavage is locally developed in the shales. In the cross-section of the Fig. 3, the Selerpe series - Lagunitas Formation boundary is a thrust plane dipping 45º to the west. Both structures, syncline and thrust, were developed under no metamorphic conditions. It is reasonable to interpret the western limb of the fold as footwall ramp of the thrust, while the eastern limb, parallel to it, can be interpreted as a flat in the footwall. Choiyoi Group layers that outcrop in the vicinity are subhorizontal (Fig. 6d) or have a very gentle dip, which rules out the possibility of an Andean age of these structures.

In the Quebrada de la Cruz de Piedra section, metric to decametric east-verging folds with steeply pluging axes are developed in N-S striking narrow bands. These folds (Fig. 6c) are deforming the Chanic cleavage (S_1) and often are accompanied by a crenulation cleavage (S_2). In the western part of the Quebrada de Cortaderas, in the overturned limb of the Chanic anticline described above, centimetric to metric folds are deforming the Chanic cleavage (S_1) and develop a crenulation cleavage (S_2). Due to their general vergence to the east, these structures can be related to the Gondwanan deformation.

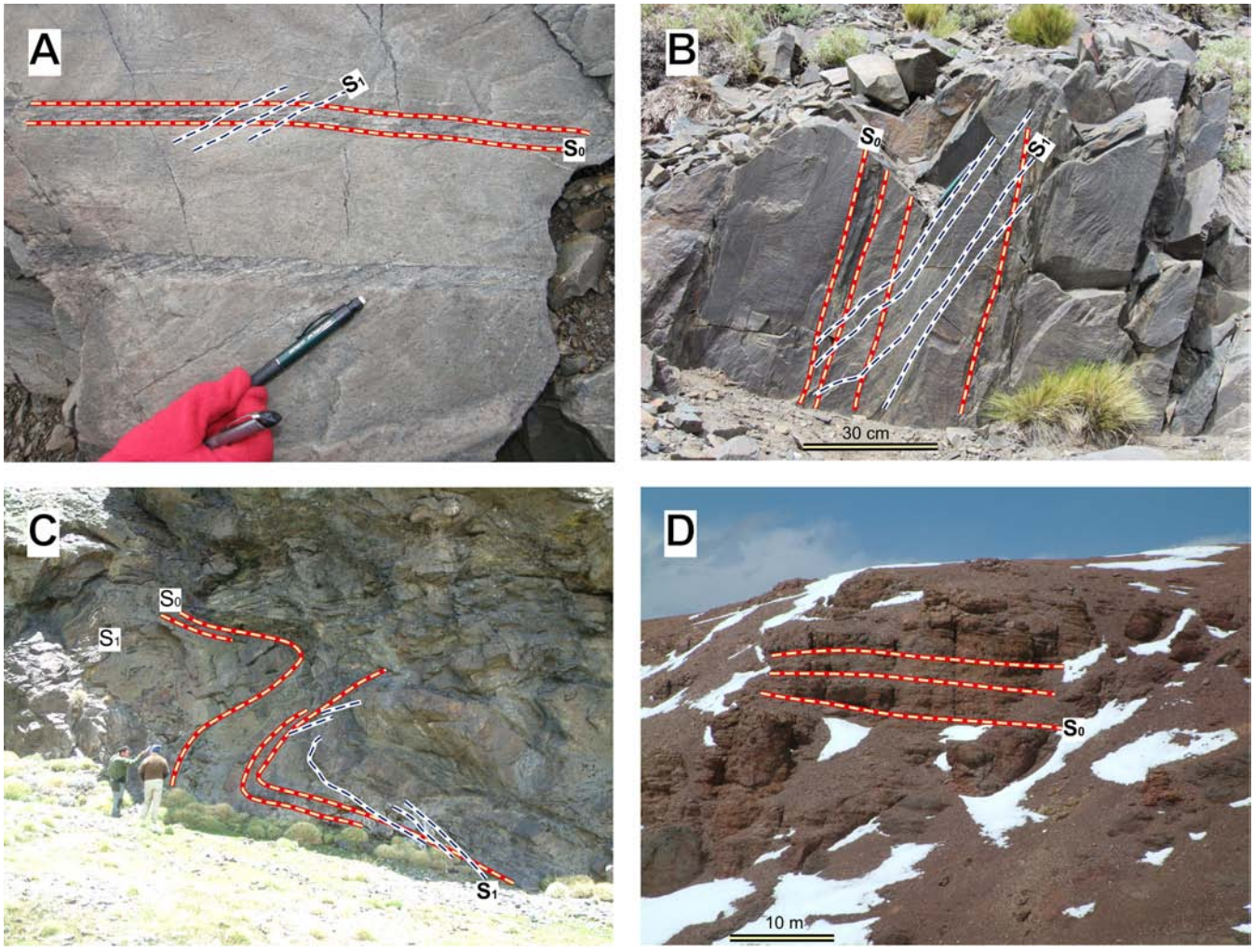

Fig. 6.- Photographs from the zone of the Cruz de Piedra river. Trend of S_1-planes within quartzites and slates in the normal limb (A) and overturned limb (B) in the Chanic anticline. (C) S_1 slaty cleavage deformed by Gondwanan folds. (D) Subhorizontal beds of the Choiyoi Group in the Pampa de los Avestruces.

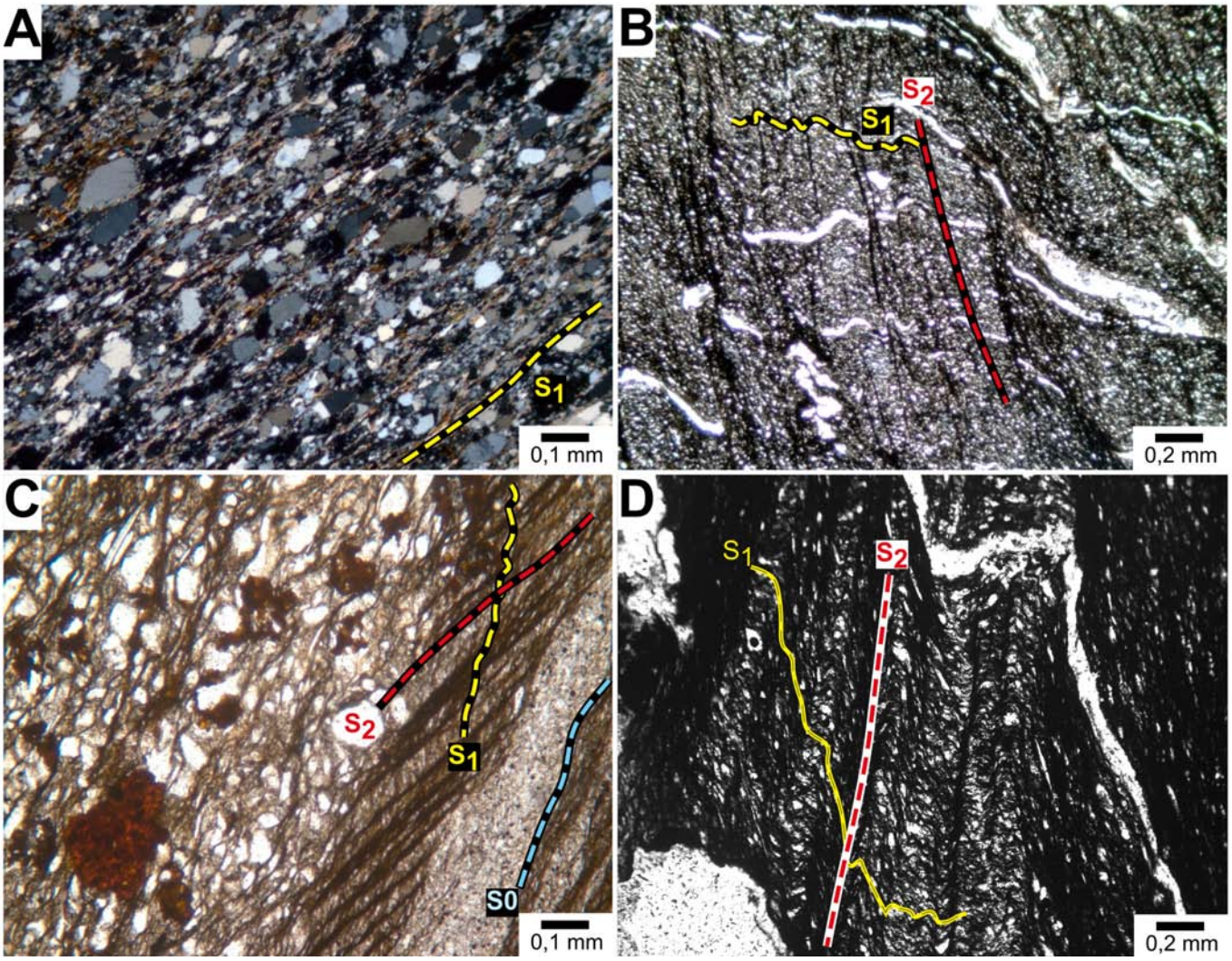

Fig. 7.- Photomicrographs of microstructures developed in the Las Lagunitas Formation. (A) Continuous cleavage (S_1) in sandstones, defined by de orientation of quartz, K'feldspar and muscovite. (B) S_2 crenulation cleavage in siltites. (C) S_0, S_1 and S_2 planes in quartz-arenites. (D) S_1 slaty cleavage and S_2 crenulaton cleavage in dark slate (quartz veins are parallel to S_1 slaty cleavage). Traces of S_0-, S_1-, and S_2-planes are indicated by blue, yellow, and red dashed lines, respectively. A, B and C: Quebrada de la Cruz de Piedra cross-section. D: Quebrada de Cortaderas cross-section.

In slate horizons, the smooth S_2 crenulation cleavage is defined by parallel and discrete domains with accumulation of opaque minerals (Fig. 7b, c, d). In quartzite layers, it only appears as a rough and spaced crenulation cleavage (Fig. 7b, c).

3.3.Andean structures

Andean structures consist mainly of gentle folds affecting the Choiyoi Group. To the west of the Quebrada de Cortaderas a sub-vertical NE-SW trending normal fault could be detected. With a downthrown of the western block it also affects the Choiyoi Group and Las Lagunitas Formation (Figs. 2, 3).

4. Geotectonic implications

In the Andean Frontal Cordillera there are many evidences pointing to the presence of structures of Chanic age. The Chanic orogeny took place as a consequence of the accretion of the Chilenia terrane to Gondwana, in the Late Devonian - early Carboniferous (Ramos *et al*., 1984). The Chanic orogen consists of two branches: (i) the western one, the Frontal Cordillera, built up on the eastern margin of Chilenia, and (ii) the eastern one, represented by the Precordillera, formed on the western margin of Gondwana (Heredia *et al*., 2012). In the Precordillera, pre-Devonian rocks with ophiolitic affinities are preserved. They can be considered as remnants of the consumed oceanic crust during the convergence between Chilenia and the west Gondwana margin. As a consequence, Chanic structures in both branches show an opposite general vergence, to the west in the Frontal Cordillera (Heredia *et al*., 2002; Heredia *et al*., 2012) and to the east in the Precordillera (Álvarez-Marrón *et al*., 2006; Alonso *et al*., 2008). The width of the western branch of the Chanic orogen is unknown, because it is partially covered by Mesozoic and Cenozoic rocks, while the eastern branch extends up to the Central Precordill-

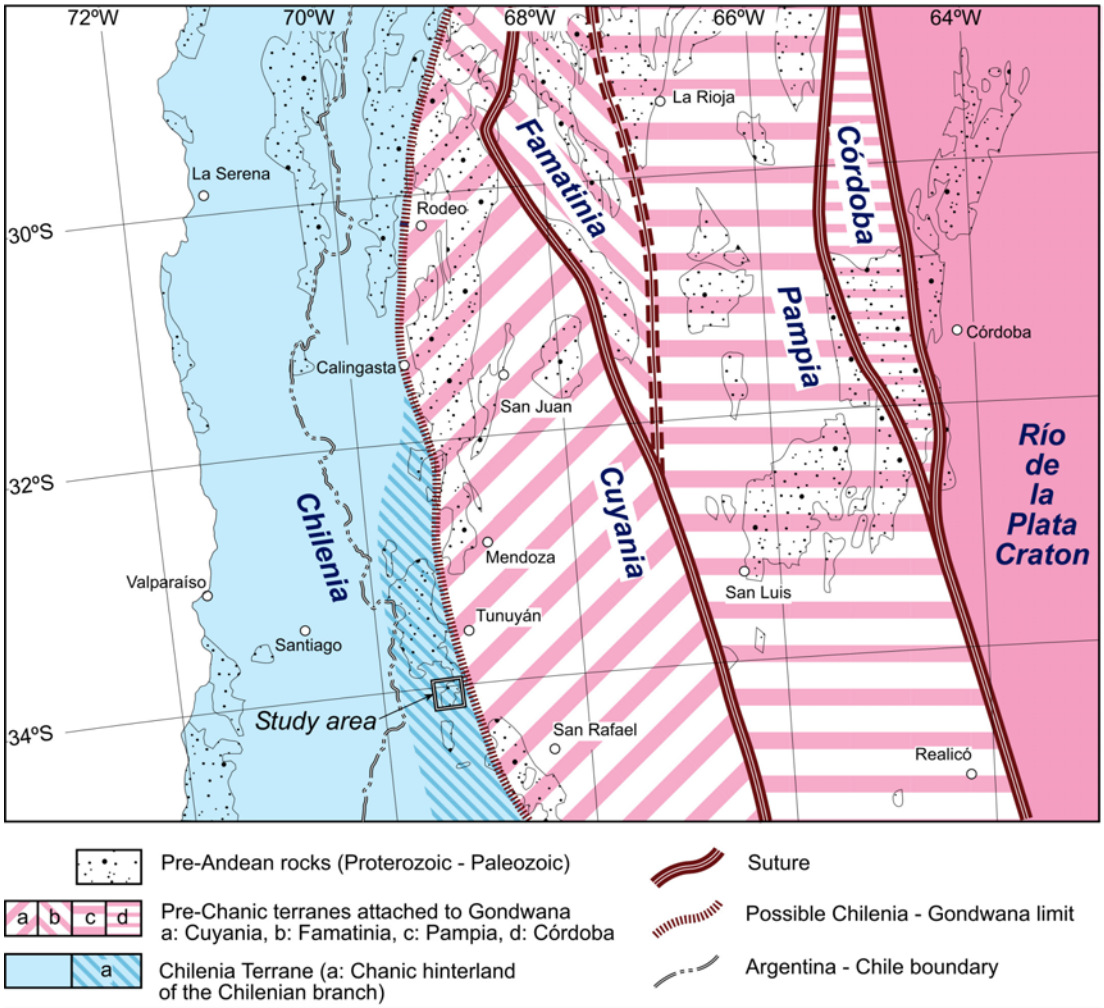

Fig. 8.- Map of the Andes between 28 and 35° S latitude, shows the location of the terranes accreted to Gondwana, and the possible position of the the hinterland - foreland boundary in the western branch of Chanic orogen. Modified from Ramos (1999, 2009) and Astini *et al*. (2011).

era, where Devonian and Carboniferous rocks show an erosional disconformity (von Gosen, 1992). Therefore, the west-directed vergence of the Chanic structures in the study area confirms that this part of the Frontal Cordillera represents the western branch of the Chanic orogen. Moreover, the low-grade metamorphic conditions during Chanic deformation and the presence of pre- and syn-orogenic granitoids (Carrizalito tonalite), early Carboniferous in age, indicate that this area forms part of the hinterland of the Chanic orogen. The foreland of this orogen should be located westwards of the study area and probably erased by ulterior magmatic activity (Fig. 8).

In the Cordon del Plata (Frontal Cordillera) (Fig. 1) the existence of conglomerates with pebbles of volcanic rocks in the Vallecitos beds (probably Devonian) allows to relate this unit with a forearc basin (Heredia *et al*., 2012). Furthermore, Lower Devonian calco-alcaline granitoids of the Pampa de los Avestruces have been interpreted as involved in a Chanic magmatic arc developed in a compressive regime before the Chilenia-Gondwana collision (Tickyj *et al*., 2009a; Tickyj, 2011). All this arguments suggest that the subduction that consumed the oceanic crust between Chilenia and Gondwana, might be located under Chilenia (Davis *et al*., 1999; Gerbi *et al*., 2002; Heredia *et al*., 2012).

After the Chilenia - Gondwana collision, a new subduction zone developed at the western margin of the Chilenia terrane (Ramos, 1988; Rebolledo and Charrier, 1994). As a result of this new tectonic context, a backarc basin developed in the Frontal Cordillera, where the sedimentation of the El Plata and Cerro de Agua Negra formations took place during the Carboniferous period (Mpodozis and Ramos, 1990; Fernández Seveso *et al*., 1993; Astini, 1996; Azcuy *et al*., 1999; Charrier *et al*., 2007). The Selerpe series, described here, must also represent sedimentation under these conditions. The compressive deformation linked to the Gondwanan episode (San Rafael orogeny) is represented by east-verging folds and thrusts, developed from the coast of Chile to the Central Precordillera (Alonso *et al*., 2005; Álvarez-Marrón *et al*., 2006; Alonso *et al*., 2008; García-Sansegundo *et al*, in this volume). Deformation took place under no- to very low-metamorphic conditions during the late Carboniferous and Early Permian.

5. Conclusions

The main conclusions of this study can be summarised as follows:

-In the Quebrada de Cortaderas, rocks previously included in the Las Lagunitas Formation (Ordovician) do not record any evidence of Chanic deformation neither appreciable metamorphism. They are in tectonic contact with the Las Lagunitas Formation. Therefore, we name these rocks as Selerpe series, with a probable late Carboniferous age.

-Two Chanic west-verging anticlines of kilometric scale affected rocks of the Las Lagunitas Formation and developed under low-grade metamorphic conditions.

-The vergence of the structures, the low-grade metamorphism and the existence of syn-orogenic granitoids (early Carboniferous in age), indicate that the Frontal Cordillera corresponds to the hinterland of the western branch of the Chanic orogen.

-The subduction that consumed the oceanic crust between Chilenia and Gondwana must be located under the Chilenia terrane, considering the presence of pre-collisional deformation affecting granitoids in the Frontal Cordillera, as well as volcanic pebbles within conglomerates of Devonian age.

-Gondwanan structures are east-verging thrusts and folds of metric-scale, affecting the Chanic structures. They developed under no- to very low-metamorphic conditions. These structures do not affect rocks of the Permian to Triassic Choiyoi Group.

-The Andean structures in the study area are gentle folds and subvertical faults deforming the Choiyoi Group beds.

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