ARTICLE IN PRESS

GR-00279; No of Pages 22

Available online at www.sciencedirect.com

ScienceDirect

Gondwana Research xx (2008) xxx–xxx

www.elsevier.com/locate/gr

Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina

Daniel A. Gregori *, José Kostadinoff, Leonardo Strazzere, Ariel Raniolo

INGEOSUR-Departamento de Geología; Universidad Nacional del Sur, and CONICET, San Juan 670, 8000 Bahía Blanca, Argentina

Received 13 October 2006; received in revised form 17 April 2008; accepted 18 April 2008

Abstract

The tectonic configuration of northern Patagonia is recognized through geological and geophysical studies, which define several areas characterized by positive and negative gravity anomalies with steep gravity gradients. Positive areas are interpreted as continental crust with Grenvillian and Pampean basement. The Pampean basement occurs to the north and south of the interpreted suture between Patagonia and Gondwana South America. Most negative anomalies are interpreted to represent Gondwana igneous and sedimentary rocks. Areas characterized by steep gravity gradients are coincident with shear zones and mylonitic belts that were active during Gondwana times, a period of great magmatic and tectonic activity in northern Patagonia. Dextral movement along the E–W-trending Huincul Fault Zone resulted in block collage, west–northwest crustal translations, and counterclockwise rotation of large crustal blocks belonging to the North Patagonia Massif. The indentation of blocks within the North Patagonia Massif resulted in tectonic escape of the surrounding blocks, each with a different trajectory. Escape tectonics may explain the diversity of stress directions during Gondwana Orogeny.

Keywords: Gondwana tectonic configuration; North Patagonia; Geophysics; Argentina

1. Introduction

The physiographic and geological differences between central Argentina and Patagonia led pioneer authors to consider Patagonia as being geologically different from South America, mainly during Gondwana time (Keidel, 1925; Windhausen, 1931, Dalmayrac et al., 1980). The transcontinental boundary between these two crustal terranes was inferred from several photolineaments, including the Huincul Fault zone, the Río Limay Lineament and the Salinas Trapalcó–Laguna Curicó Lineament (Fig. 1) (Turner and Baldis, 1978).

The zone where this interpreted boundary is located is covered by two Mesozoic basins and Tertiary–Quaternary sediments (Figs 1 and 2). There are no outcrops of Neopaleozoic rocks and thus the geological configuration at that time is unknown. Permo-Triassic igneous rocks in the North Patagonia Massif and the Carboniferous marine Tepuel Basin occur to the south of the proposed boundary. To the north of the boundary are several Carboniferous marine and continental basins occur (Andacollo, El Imperial, Carapacha, and Claromecó), Contemporaneous igneous complexes are located in the Chadí Leuvú and San Rafael Blocks, which are also located to the north of the boundary (Fig. 1).

Cambrian rocks (Pampean Orogeny) are widely represented in north-central Argentina (Sierras Pampeanas de San Luis and Córdoba, Figs 1 and 2) and crop out directly north of the boundary, in the Rio Colorado High (Kostadinoff et al., 2005). Discontinuous outcrops together with gravimetric surveys (Delpino et al., 2005) in this area, allow correlation between the Río Colorado High and the outcrops of the Sierras Pampeanas.

In the North Patagonian Massif, Pampean rocks are represented by the El Jaguelito and Nahuel Niyeu Formations (González et al., 2002), but the connection with the Rio Colorado High throughout the hypothetical boundary is not clear due to the Quaternary cover (Figs 2 and 3). Sedimentary rocks deposited in Upper Cambrian to Devonian marine basins (Famatinian Orogeny) also crop out to the north (Sierras Australes)

* Corresponding author. Tel.: +54 291 4515901x3031; fax: +54 291 4595148.
E-mail address: usgregor@criba.edu.ar (D.A. Gregori).

1342-937X/$ - see front matter
doi:10.1016/j.gr.2008.04.005

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

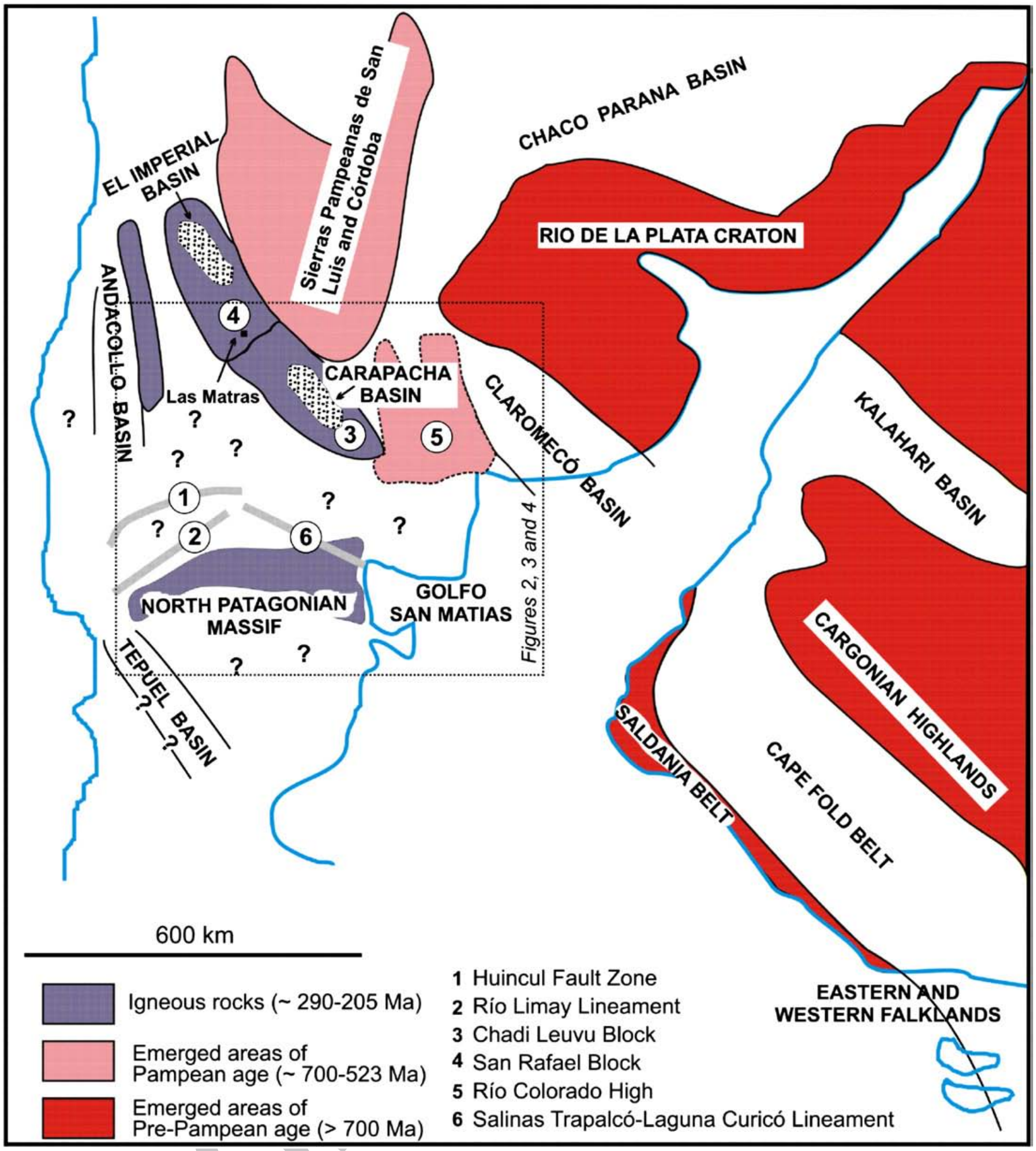


Fig. 1. Configuration of western Gondwana showing location of Neopaleozoic basins, positive areas (3, 4 and 5), major structural lineaments (1, 2 and 6) and areas with active magmatism. Major positives areas are represented by Precambrian cratons, the Sierras Pampeanas and Colorado High. Question marks indicate sectors where the geological configuration is unknown.

and to the south (Sierra Grande) of the boundary (Figs 2 and 3), however, correlation between these basins is uncertain because they are covered by Tertiary–Quaternary sediments.

In order to explain the differences between central Argentina and Patagonia, Ramos (1984) proposed that Patagonia represent an allochthonous terrane separated from Gondwana–South America by a marine basin before Carboniferous times. This terrane approached Gondwana–South America, initiating north–south directed subduction with a final stage of collision between both continental blocks in the Permian. The subduction stage produced Permo-Triassic arc-related magmatism in the North Patagonia Massif, while the terrane accretion produced intense Permian folding and thrusting in the Sierras Australes.

There are several doubts about this hypothesis. For example, no outcrops of basic-ultramafic rocks with oceanic crustal affinities have been found. The pattern of the gravimetric and magnetic anomalies (Kostadinoff and Labudía, 1991, Kostadinoff et al. 2005) north, south and over the proposed boundary are incompatible with the existence of a belt of high-density rocks below the Quaternary cover, as would be expected in the Ramos (1984) hypothesis. Paleomagnetic studies by Rapalini (1998) in the Famatinian rocks of the North Patagonian Massif (Silurian–Devonian Sierra Grande Formation) indicate that Patagonia has not undergone latitudinal displacements relative to South America since Devonian times. The continuity of the Pampean belt southwards of the supposed boundary (González et al., 2002; Rapela and Pankhurst, 2002; Kostadinoff et al., 2005) is also at odds with the tectonic model of Ramos (1984).

Additionally, several authors (e.g., Rapalini and Vizán, 1993, Rosello et al., 1997) have interpreted the Gondwana deformation in the Sierras Australes and North Patagonian Massif as resulting from intraplate compression. This deformational event is also

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

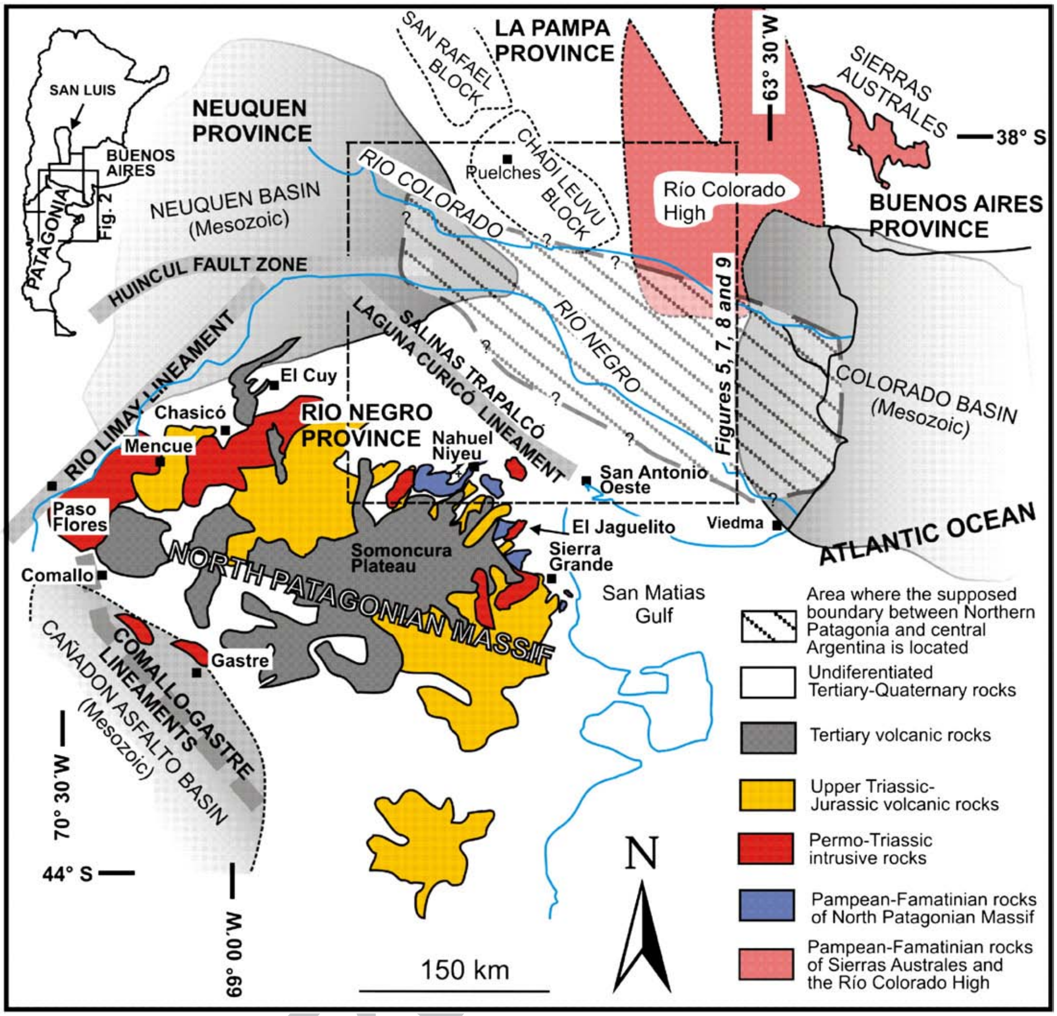


Fig. 2. Major geological features of northern Patagonia. The area where the supposed boundary between central Argentina and Patagonia is located is covered with Tertiary–Quaternary deposits. The eastern and western ends of this zone are occupied by Jurassic–Cretaceous sediments of the Colorado and Neuquén Basin. Minor outcrops are Pampean and Famatinian rocks. Gondwana intrusive and volcanic igneous rocks are located in central and western North Patagonian Massif. Jurassic and Tertiary volcanic rocks cover large areas of this Massif, precluding stratigraphic correlations.

preserved in the Cape Fold Belt (South Africa), the Malvinas (Falkland) Islands, and in Antarctica and constitutes the 'Samfrau Orogenic Zone' (Söhnge, 1983, Davidson et al., 1987, Dalziel et al., 1987).

The aim of this paper is to investigate the existence of suture zone or terrane boundary between northern Patagonia and central Argentina to test the tectonic model of Ramos (1984). If a suture exists between the Patagonia and continental South America, we aim to better understand its nature and define the tectonic configuration of northern Patagonia during Gondwana times. In order to investigate the geological configuration between the North Patagonian Massif and central Argentina, we undertook geophysical and geological studies in northern Patagonia.

2. Geological background

2.1. Pampean rocks (Neoproterozoic–Middle Cambrian)

Rocks assigned to the Pampean Orogeny (Late Proterozoic–Middle Cambrian) are widely distributed in central Argentina (Sierras Pampeanas de San Luis and Córdoba, Fig. 1), but are scarce in northern Patagonia (Figs 2 and 3). Low-grade phyllite and metasandstone within the La Pampa Province are interpreted as part of the Las Piedras Metamorphic Complex by Tickyj et al. (1999). Correlation between the La Pampa Province and central Argentina was established by radiometric dating (Linares et al., 1980) and gravimetric data, which demonstrated the presence of a north–south trending belt in the subsurface (Figs 1–3) connecting the La Pampa province outcrops with those of the Sierras de San Luis and Córdoba (Kostadinoff et al., 2001, Delpino et al., 2005).

In the south part of the La Pampa province, near the supposed boundary, a gravimetric study showed the existence of a positive east–west trending residual gravity anomaly (Figs 3 and 7) coincident with outcrops of Pampean rocks (Kostadinoff et al., 2005). This anomaly crosses the proposed northern Patagonia boundary (Kostadinoff et al., 2005), which suggests that the belt of Pampean rocks of central Argentina continues in the subsurface (Fig. 3) into northern Patagonia (Río Colorado, Choele Choel). In the north-eastern sector of the North Patagonian

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

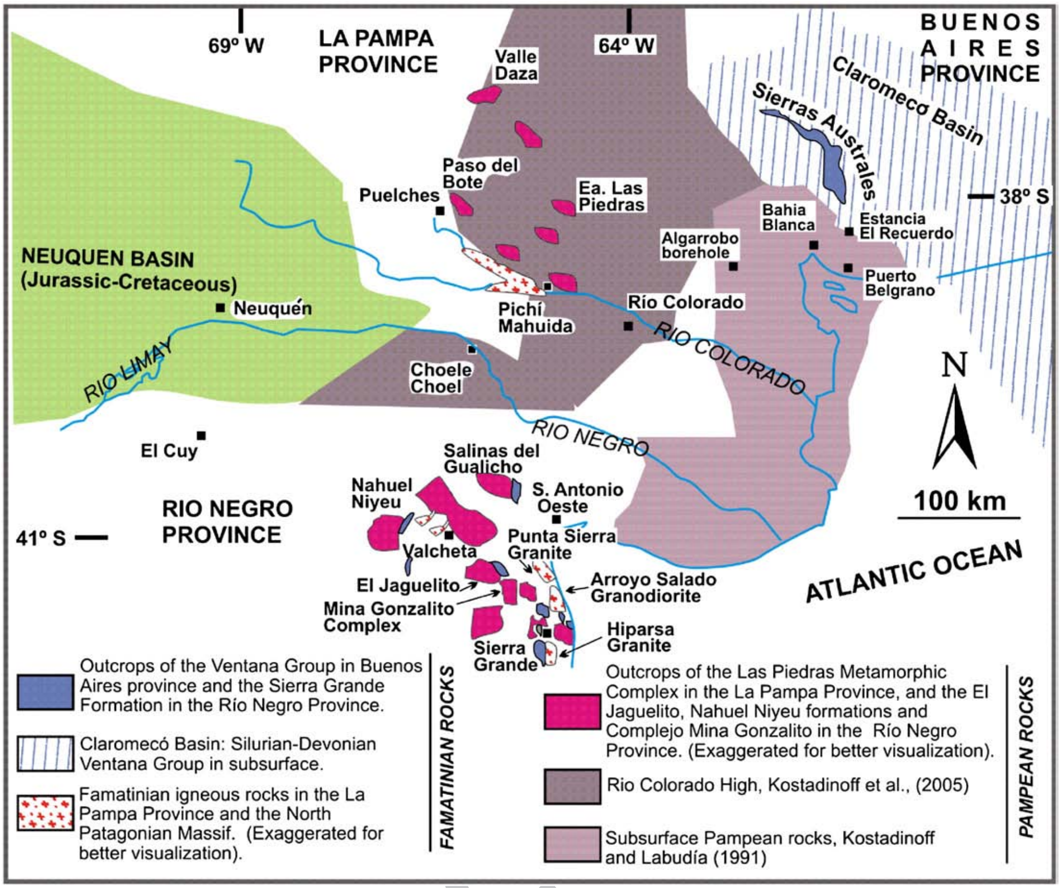


Fig. 3. Distribution of outcrops and subsurface arrangement of the Pampean–Famatinian rocks. The Río Colorado High, as defined by Kostadinoff et al. (2005) is located in the southern and central parts of the La Pampa Province. The western border of the Famatinian Claromecó Basin, also of Pampean age, was established by Kostadinoff and Labudía (1991). The Algarrobo borehole found Pampean rocks of this positive area. Outcrops of the Famatinian igneous rocks are scarce both north and south of the supposed boundary.

Massif, previous gravimetric data across the interpreted suture zone showed the existence of anomalies interpreted to be the Pampean low-grade phyllite and metasandstone intersected in the Algarrobo borehole (Fig. 3) (Kostadinoff and Labudía, 1991).

In the North Patagonian Massif, low and medium-grade metamorphic rocks are more abundant than in the La Pampa Province. The El Jaguelito and Nahuel Niyeu formations and the Mina Gonzalito Complex consist of phyllite, metasandstone, marl, amphibolite and limestone. Fossil remains analogous to those of the Pampean rocks of central Argentina occur in the El Jaguelito Formation (González et al., 2002). Radiometric dating (U/Pb) using detritial zircons indicate ages of >535 Ma for the El Jaguelito Formation, >515 Ma for the Nahuel Niyeu Formation and >535–540 Ma for the Mina Gonzalito Complex (Pankhurst et al., 2006), which were deformed and metamorphosed during the Pampean Orogeny (Dickerson, 2004).

2.2. Famatinian rocks (Upper Cambrian–Devonian)

Famatinian sedimentary rocks (Ventana Group) occur in the Sierras Australes and the Claromecó Basin (Buenos Aires province), located to the north of the proposed Patagonia boundary (Fig. 3). They comprise mainly quarzite with minor conglomerate and pelite deposited in a marine platform environment. These units have been linked to the Table Mountain and Bokkeveld groups within the Cape Fold Belt in South Africa (Keidel 1916, Keidel 1925), and sedimentary successions on the Malvinas (Falkland) Islands and the Ellsworth Mountains (Antarctica) (Buggisch, 1987).

In the North Patagonian Massif the Sierra Grande Formation has similar lithologies, paleofauna, and deformation characteristics as the Ventana Group of the Sierras Australes. These similarities suggest that both units were deposited in the same basin, part of which is now buried underneath the Mesozoic Colorado basin.

Famatinian granites are represented in La Pampa Province by the Pichí Mahuida Group (Fig. 3), which is dated between 431±12 and 397±25 Ma (Sato et al., 1996, Tyckyj et al., 2002). These dates are similar to the Famatinian magmatic event of the Sierras Pampeanas de San Luis (Sato et al., 1996). In the North Patagonian Massif (Fig. 3), this magmatic event is represented by the Arroyo Salado Granodiorite (476±4 Ma, U/Pb zircon and 467±16 Ma, Rb/Sr), Hiparsa Granite (357±57 Ma, Rb/Sr) and the Punta Sierra Granite (483±22 Ma, Rb/Sr, Varela et al. 1998).

The timing of Famatinian deformation and metamorphism in the North Patagonian Massif is constrained by an Arenigian age (ca 472 Ma) obtained from U/Pb analysis of metamorphic zircon (Pankhurst et al., 2006) from schists of the Mina Gonzalito Complex. Deformation associated with this event is typical of central Argentina and suggests continuity of the Famatinian Belt into northern Patagonia (Pankhurst et al., 2001).

2.3. Gondwana rocks

In La Pampa Province the Gondwana magmatic rocks crop out as a NW–SE trending belt (Figs 1 and 4) that extends from the San Rafael and Chadí Leuvú Blocks to López Lecube (Linares et al., 1980, Llambías and Leveratto, 1975, Llambías et al., 1996, Gregori et al., 2003). Sedimentary successions deposited in a continental setting form the small Carapacha Basin in the La Pampa Province (Fig. 4). In the Sierras Australes and the Claromecó Basin (Figs 1 and 4) occurs glacio-marine to fluvial sedimentary sequences of the Permo-Carboniferous Pillahuincó Group. These basins display lithological and structural features similar to the Karoo Basin in South Africa (Keidel, 1916).

In the North Patagonian Massif, magmatic rocks are widely represented by three separate belts that are oriented SW–NE, W–E and NW–SE. The NW–SE trending belt is present in the studied area and extends from Yaminué to the Atlantic coast (Fig. 4). Foliated granites (Yaminué, Tapera, María Teresa, Laguna Medina, Peñas Blancas and La Laguna) and non-foliated plutonic complexes (Donosa, Calvo, Navarrete, Flores, Pailemán, Tembrao, La Verde) outcrop along the belt (Llambías and Rapela, 1984, Rapela and Caminos, 1987, Grecco et al., 1994, Giacosa, 1997).

Several small Middle to Upper Triassic continental rifts are located in the Los Menucos and the Comallo areas. These rifts mainly contain pyroclastic deposits (Fig. 4).

3. Geophysics

Few geophysical surveys have been carried out south of the Colorado and Negro rivers (Fig. 2). Chernicoff and Zappettini (2004a,b) undertook aeromagnetic studies to the east and west of Choele Choel (Fig. 3), whereas Kostadinoff et al. (2005)

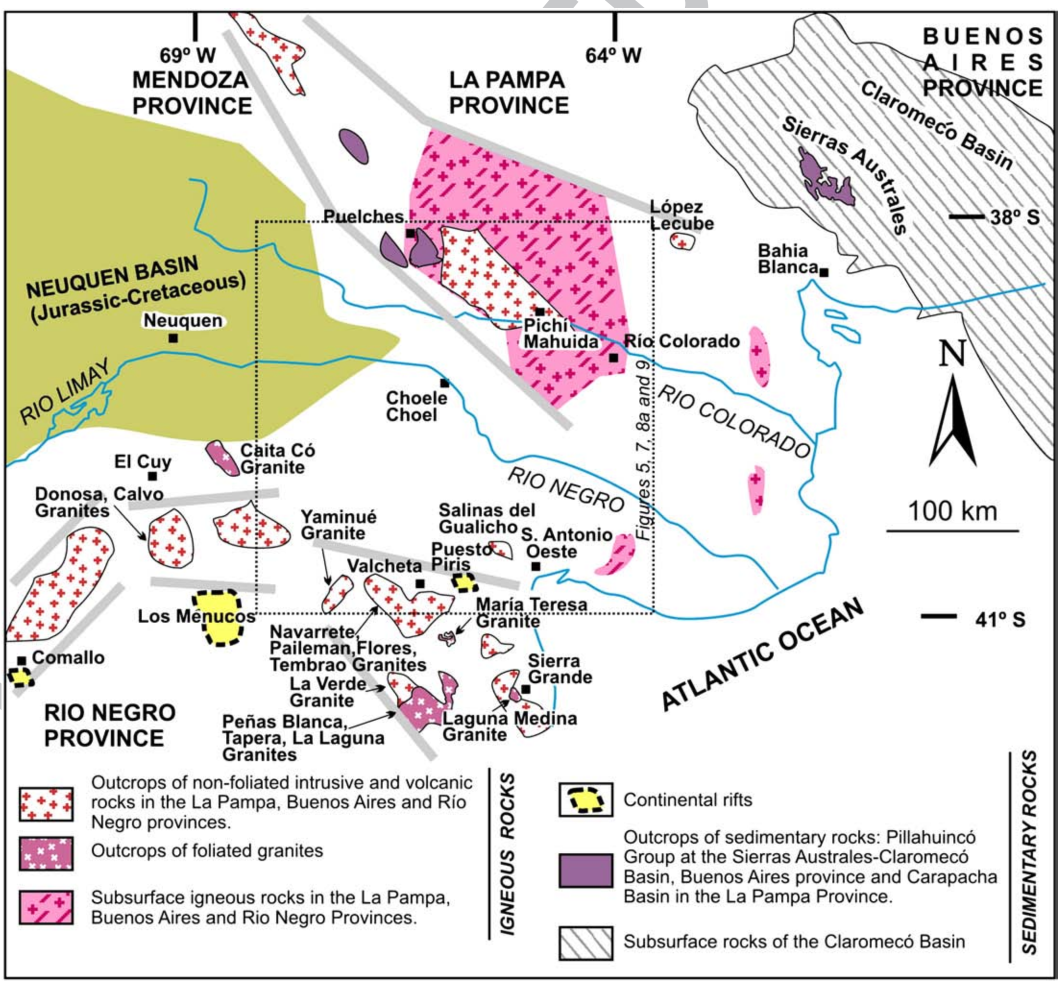


Fig. 4. Distribution of Neopaleozoic basins and igneous rocks. The Claromecó Basin, Sierra Australes and the Carapacha Basin, formed in glacio-marine and fluvial environments are located north of the supposed boundary. No marine sedimentary basins were recognized south, but igneous rocks outcrop extensively along three main belts. North of Colorado River the outcrops have a NW–SE trend. Triassic continental depocenters were developed in the eastern (Puesto Piris), central (Los Menucos) and western (Comallo–Paso Flores) parts of northern Patagonia.

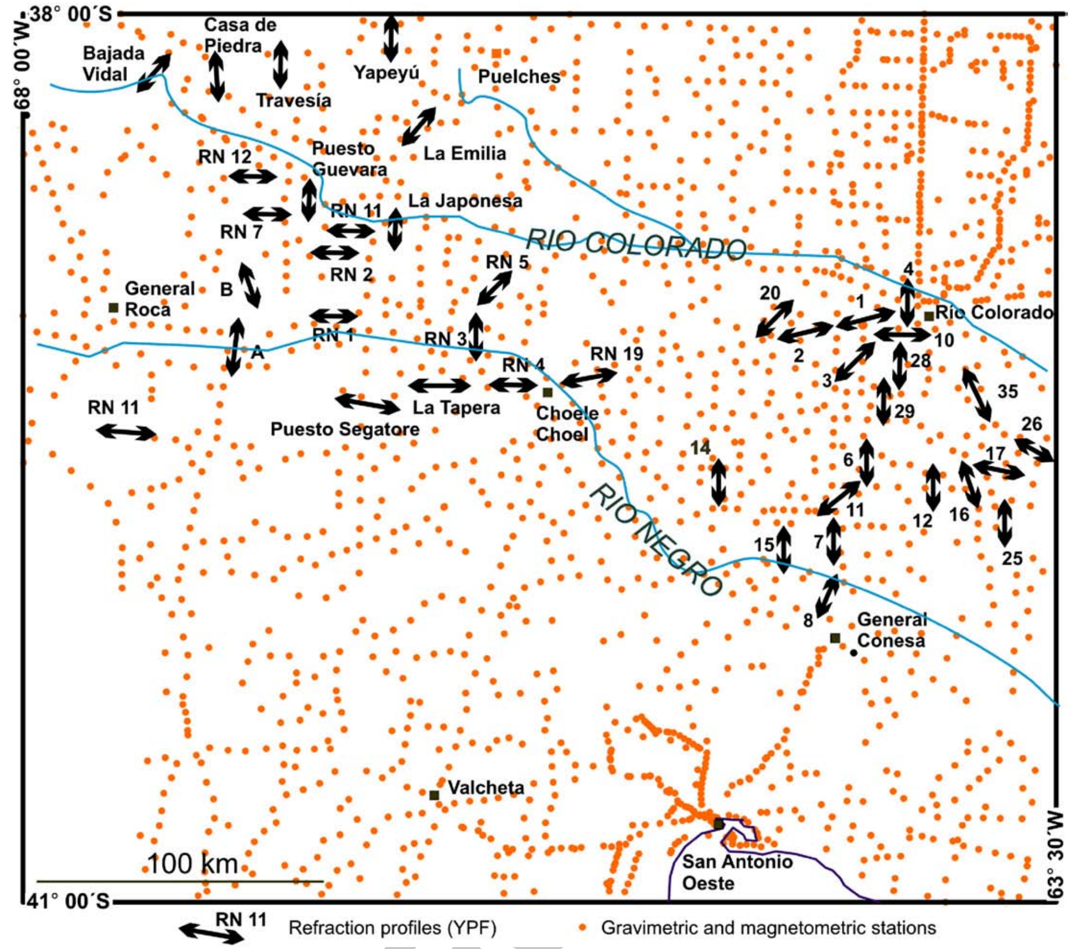


Fig. 5. Location of the 1647 stations where gravity and magnetic measurements were done during a 4 years project. Refraction shots by YPF are also displayed.

described several gravimetric and magnetic anomalies, as well as the continuation of the Huincul Fault zone and the Choele Choel High (Figs. 3 and 10). Unpublished internal reports on seismic surveys by Yacimientos Petrolíferos Fiscales (YPF) provide information about the subsurface architecture in this region. Seismic survey locations are shown in Fig. 5. Seismic velocities, lithological and age interpretations are based on correlations with boreholes and reflection profiling in the Neuquén Basin (Orchuela and Ploszkiewicz, 1984, Cabaleiro et al., 2002) (Fig. 6).

We report here additional geophysical measurements that help to constrain geology and tectonics in this region. Magnetic data were collected using a G-856 proton precession magnetometer. The daily geomagnetic variation and the International Geomagnetic Reference Field values were used to calculate magnetic anomalies. Gravity measurements were carried out using a Worden gravimeter. Both, gravity and magnetic measurements were done on benchmarks of the Instituto Geográfico Militar and Servicio Geológico Argentino, whose elevation precision vary between 1 and 30 cm.

A total of 1647 gravimetric stations and magnetic measurements were collected in the La Pampa Province and the Río Negro Province. Geographic positions of the stations were determined using GPS. Locations and distribution of the new gravity and magnetic measurements are shown in Fig. 5. The resulting residual anomaly map (Fig. 7A) allowed us to compare known geology with specific gravity signatures. Residual anomalies were obtained after subtracting the regional gravity response (which is mostly attributed to the isostatic effects associated to the slow postglacial uplift of Patagonia) from the Bouguer gravity anomaly map. Density and magnetic susceptibility determinations (Table 1) were carried out at Universidad Nacional del Sur on representative samples from the survey area. Magnetic susceptibility was measured in situ. Gravimetric gradients were calculated using Surfer 8™.

4. Results

Three areas with positive gravimetric anomalies, four with negative anomalies and several features characterized by steep gravity gradients (Figs 7A and 8A, B) were recognized during this study.

4.1. Positive anomalies

4.1.1. Chimpay–Gobernador Duval High

Residual anomalies within the range −27 to −14 mGal, a relatively positive anomaly occur from Chimpay to Gobernador

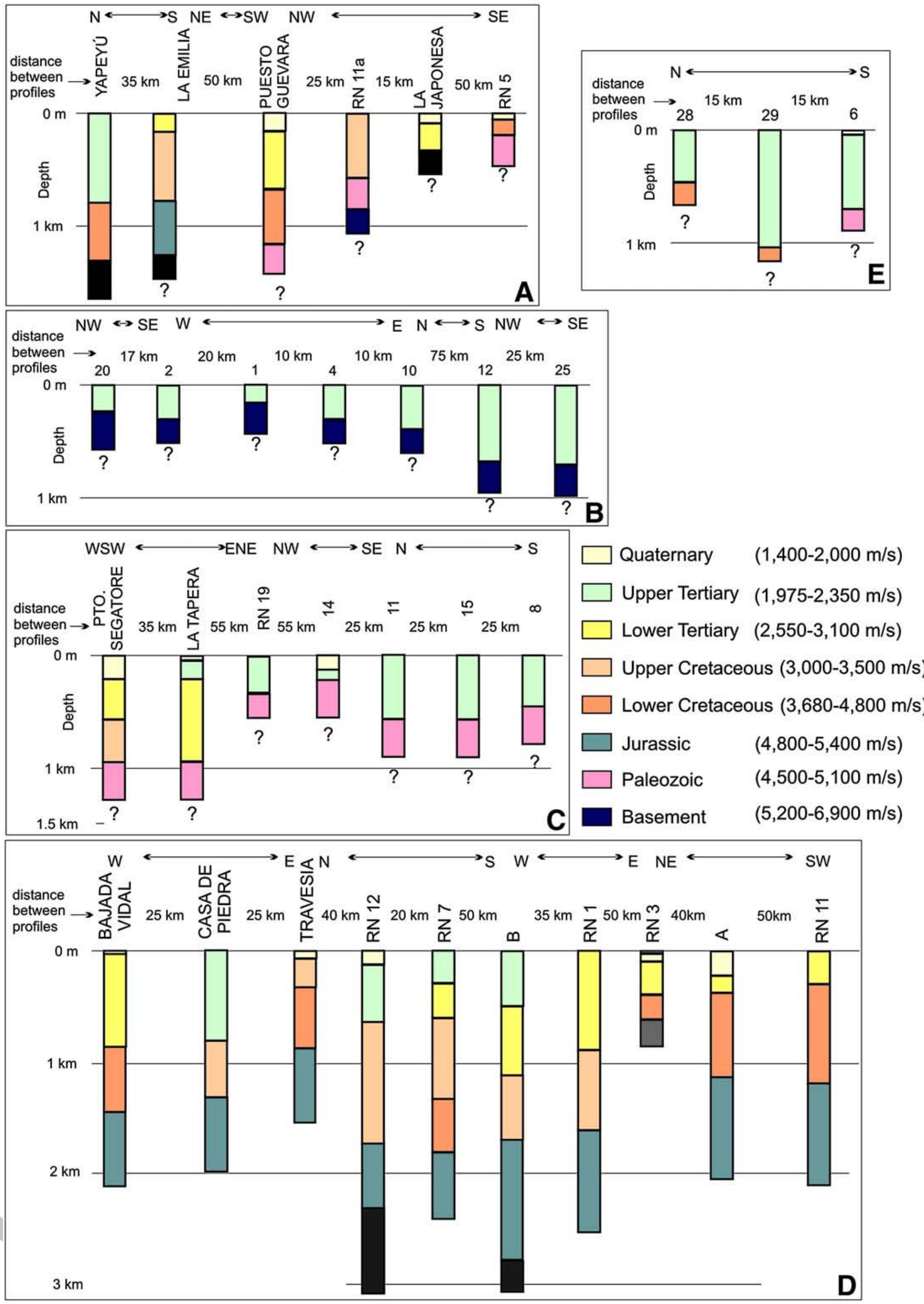
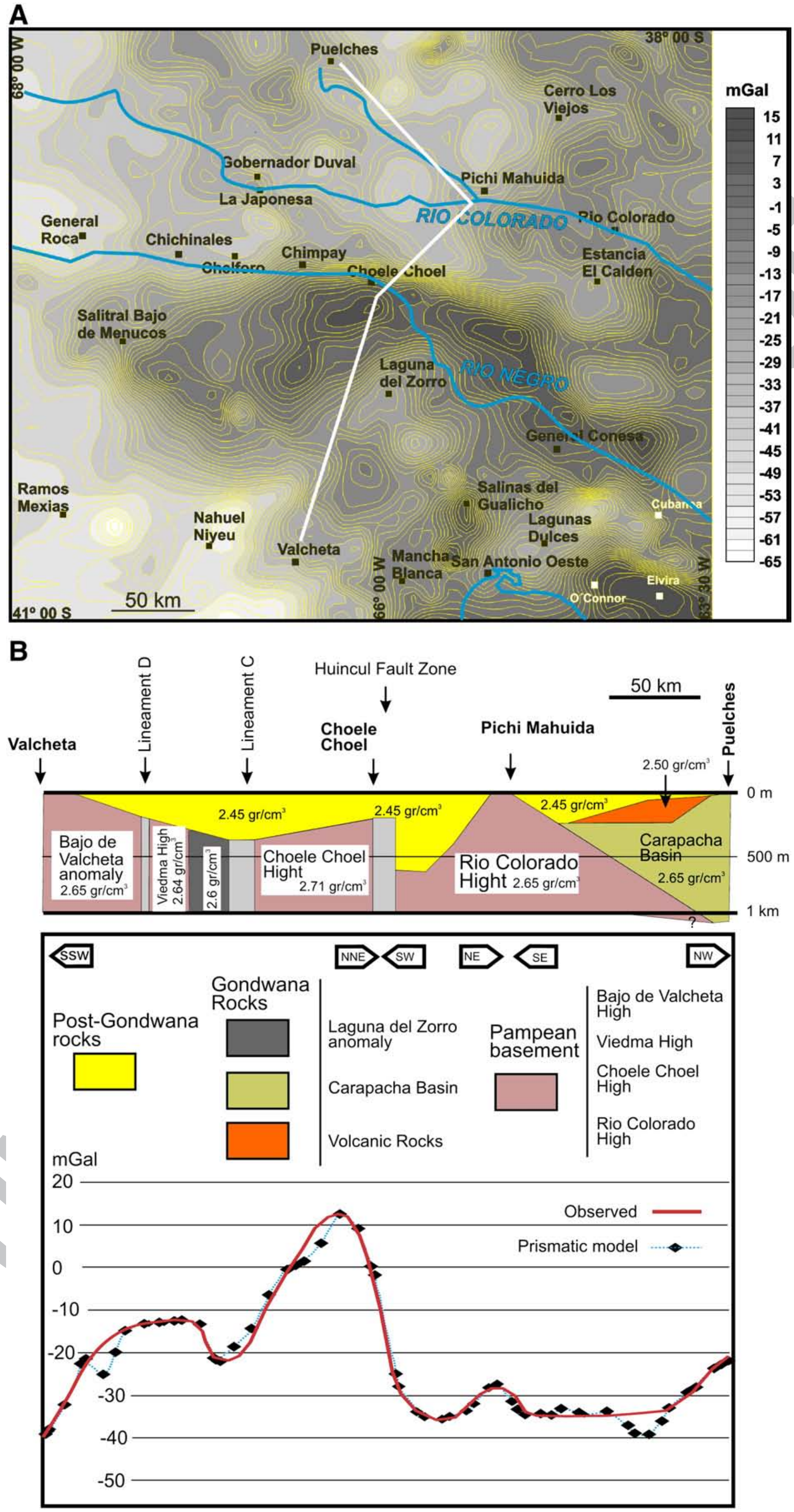


Fig. 6. A) Refraction shots (YPF) in the Chimpay–Gobernador Duval High. Basement rocks with seismic velocities up to 6600 m/s are compatible with the presence of a Grenvillian basement composed by tonalitic rocks. B) Refraction shots (YPF) in the Río Colorado High. Basement rocks, mainly of Pampean age are covered by small thickness of Tertiary–Quaternary sedimentary rocks. C) In the Choele Choel High the basement depth show a more irregular configuration, possibly related to faulting. D) Refraction shoots in the Neuquén Basin, showing the thickness of the Mesozoic sequences. Basement exhibits seismic velocities in the order of 5500 m/s. E) In the El Caldén Basin only Upper Cretaceous–Tertiary rocks were detected.

Duval and Puelén (Fig. 7). Refraction shots by the YPF (Yapeyú to RN5, Fig. 6A) indicate a thickness of more than 1000 m for the Mesozoic Neuquén Basin near Gobernador Duval. In the Chimpay–La Japonesa area this basin reaches a maximum thickness of 300 m. In order to satisfy the observed anomalies a density contrast of +0.32 g/cm^3 between the Mesozoic sedimentary rocks and those of the basement (Table 1) is required. No outcrops of basement rocks with such high density were

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005



Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

Table 1
Densities and magnetic susceptibilities

Age	Unit	Lithology	Density (gr/cm^3)	Magnetic susceptibility
La Pampa Province				
Tertiary	Río Negro Formation	Sandstones	2.45	Not determined
Cretaceous	Neuquén Group	Sandstones	2.55	Not determined
Jurassic	Mendoza Group	Pelite	2.50	Not determined
Jurassic	Lihuel Calel Rhyolites	Rhyolite	2.58	Not determined
Jurassic	Lihuel Calel Rhyolites	Rhyolite	2.61	Not determined
Jurassic	Lihuel Calel Rhyolites	Rhyolite	2.60	Not determined
Permian	Carapacha Formation	Sandstone	2.65	Not determined
Permian	Carapacha Formation	Sandstone	2.67	Not determined
Ordovician	San Jorge Formation	Limestone	2.71	Not determined
Cambrian	Los Viejos Granite	Granite	2.61	Not determined
Cambrian	Los Viejos Granite	Granite	2.60	Not determined
Cambrian	Los Viejos Granite	Granite	2.60	Not determined
Cambrian	Las Piedras Complex	Pelite	2.63	Not determined
Cambrian	Las Piedras Complex	Pelite	2.64	Not determined
Grenvillian	Las Matras Complex	Tonalite	2.89	Not determined
Río Negro Province				
Tertiary	Somoncura Formation	Basaltic lava flow	2.48	0.006500
Tertiary	Somoncura Formation	Basaltic lava flow	2.62	0.007000
Tertiary	Somoncura Formation	Basaltic lava flow	2.53	0.001240
Jurassic	Marifil Complex	Rhyolite lava flow	2.33	0.000120
Permian	Yaminué Granite	Granite	2.55	0.000350
Permian	Navarrete Granite	Granite	2.53	0.000090
Silurian–Devonian	Sierra Grande Formation	Quartzite	2.57	0.0
Silurian–Devonian	Sierra Grande Formation	Quartzite	2.55	0.0
Cambrian	Nahuel Niyeu Formation	Pelite	2.65	0.000130
Cambrian	Nahuel Niyeu Formation	Pelite	2.70	0.000280
Cambrian	El Jaguelito Formation	Pelite	2.56	0.000190

detected in the Neuquén Basin. However, Grenvillian (~1.0 Ga) basement composed of tonalite and trondhjemite were studied by Sato et al. (2000) in the Las Matras area (Fig 1), which is located 130 km north of Gobernador Duval. We interpret the Chimpay–Gobernador Duval High to be composed of basic-intermediate rocks (seismic velocity 5400–6600 m/s) covered by sedimentary rocks deposited in the Jurassic–Cretaceous Neuquén Basin. Such igneous rocks could also explain positive magnetic anomalies, which range between 250 and 175 nT (Fig. 9) in this area.

4.1.2. Río Colorado High

Several relatively positive residual gravity anomalies (6, −8 and −11 mGal) appears between Pichí Mahuida, Cerro Los Viejos and Río Colorado (Kostadinoff and Llambías (2002) (Fig. 7A). These anomalies are considered to reflect Pampean basement, which is composed of small outcrops of amphibolite, gneiss, micaceous schist, phyllite and metasandstone of the Las Piedras Metamorphic Complex and granite and granodiorite of the Pichí Mahuida Group (Linares et al., 1980; Tickyj et al., 2002). The anomalies are due to relative uplift of blocks similar to those that occur in the Sierras Pampeanas de San Luis y Córdoba. The NW–SE margin of Río Colorado High is coincident with a steep gravity gradient (near 1 mGal/km) between Cerro Los Viejos and 38° S (Figs 7A and 8A, B). Fig. 7B shows the measured and the modeled anomalies in the Río Colorado High considering a density of 2.65 g/cm^3 for the basement rocks. According to the geometries of the anomalies and the outcrops, the Río Colorado High is believed to represent a block-faulted system.

Refraction shots by YPF (numbers 20 to 25, Fig.6B) show the existence of basement rocks with high seismic velocity (5000 to 6000 m/s), which are interpreted as the Las Piedras Complex. This basement deepens to the south, reaching 700 m below the surface near the Huincul Fault zone. Magnetic anomalies are relatively low in this area and suggest the absence of paramagnetic rocks in the basement (Fig. 9).

4.1.3. Choele Choel High

The Choele Choel High (Kostadinoff et al., 2005) is a positive residual gravity anomaly of +10 and +15 mGal (Fig. 7A and B) with steep (2 mGal/km) gradients (Fig. 8A, B). The northern boundary is defined by the Huincul Fault Zone and lineament

Fig. 7. A) Residual anomalies map showing distribution of positive and negative anomalies. The kidney-form anomaly known as the Choele Choel High (Kostadinoff et al., 2005) is clearly distinguishable. The Neuquén and Carapacha basins appear as negative anomalies. The north-eastern border of the Ramos Mexías anomaly is evidently demarked. The white line represents the profile modeled in Fig. 7B. B) Gravity modeled N–S profile from Carapacha Basin to the Bajo de Valcheta anomaly. The geological configuration was obtained from data of surface geology and seismic profiles. The measured densities and the size of the rock bodies were used to compute prismatic model (Heiland, 1951). Note that similar densities were used for the Pampean basement. Measured and modeled anomalies show good adjustment.

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

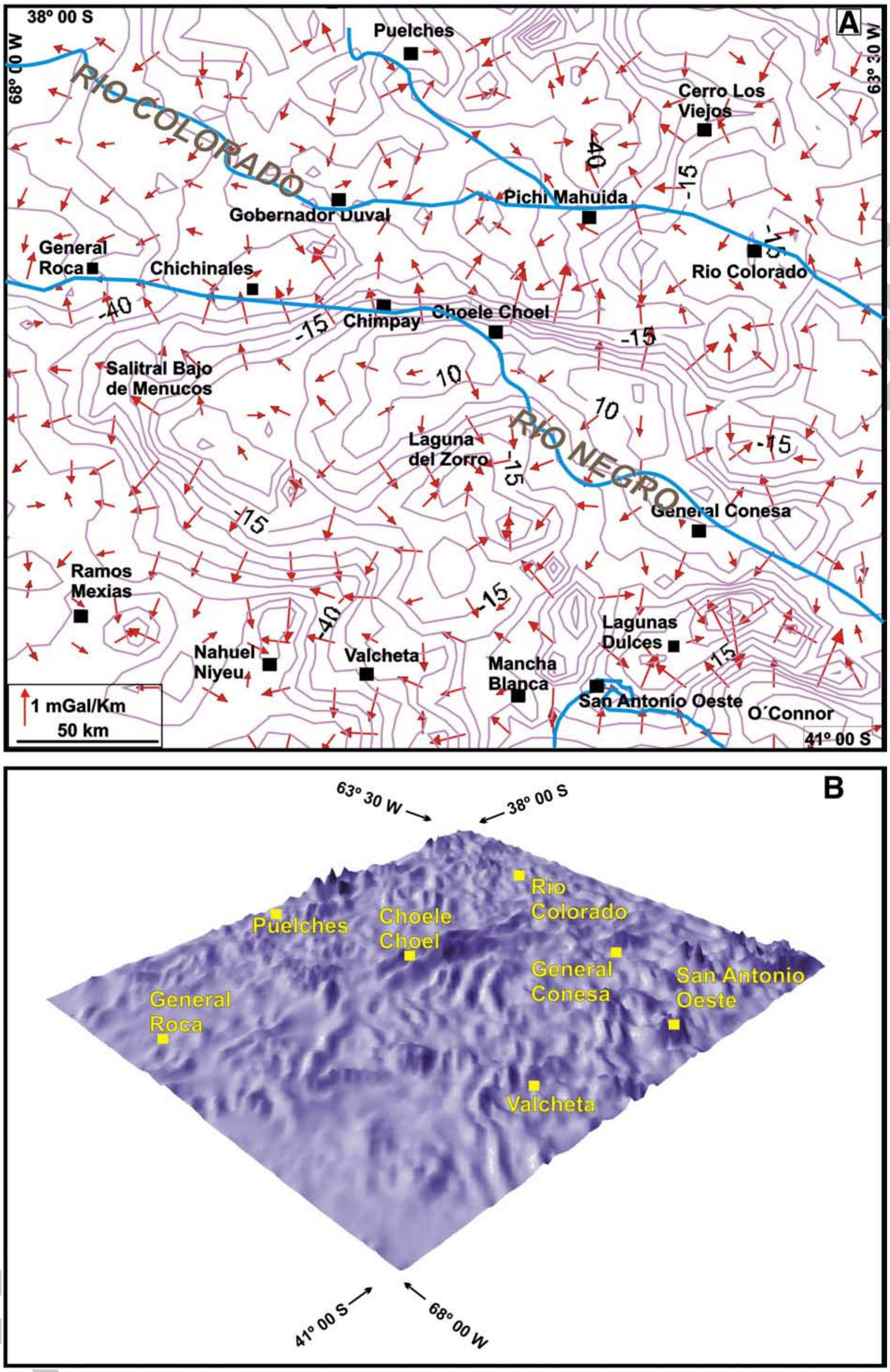


Fig. 8. A) Map showing direction and magnitude of the vectors that represent gravity gradients. Major ones are related to the Huincul Fault Zone and the NW and SW borders of the Choele Choel High. B) 3-D model produced by the second derivate operator, showing the configuration and distribution of the lineaments. The Huincul Fault zone and the borders of the Choele Choel High are evident.

"A" (Kostadinoff et al. 2005). The southern boundary (Figs 7A, B, 8 and 10) is a complex, arcuate system that is formed by 3 lineaments, which are defined by steep (1–2 mGal/km) gravity gradients (B, C and E: Fig. 10). The model of Fig. 7B requires a slighter increase in the basement rocks density to explain the measured anomaly and as showed in this figure the Choele Choel High represent an uplifted block.

Refraction shots by YPF in this area (Puesto Segatore to profile number 8, Fig. 6C) indicate the existence of rocks with seismic velocities of 4500 to 5320 m/s which are covered by Mesozoic–Cenozoic rocks. Such rocks exist at depths between 200 and 600 m in the eastern and southeastern parts of the Choele Choel High (Profiles 8 to RN19) and to a depth of 1000 m when approaching lineament "A".

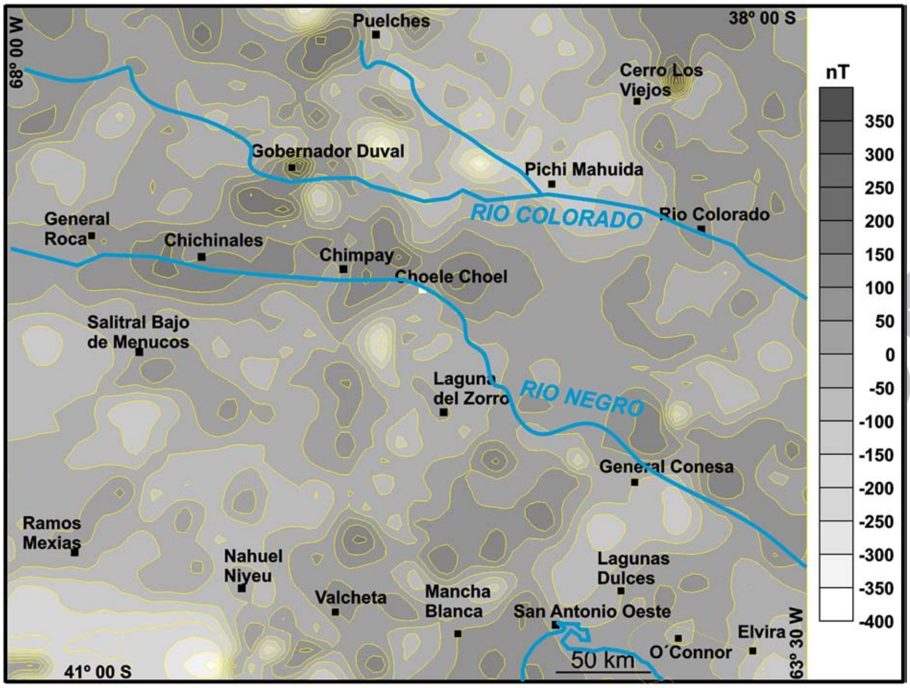


Fig. 9. Map showing distribution of the magnetic anomalies. No obvious correlation with Bouguer anomalies was observed. Most anomalies are discontinuous and segmented.

Candidates that fulfil such seismic velocity are the phyllite, muscovite-bearing schist, and metasandstone of the Las Piedras Complex that are exposed in the Río Colorado High. The seismic velocities may also be explained by phyllite, metasandstone, marble and pelite of the Nahuel Niyeu and El Jaguelito formations (Fig. 3), which are temporally correlated with the Las Piedras Complex, and crop out in the Nahuel Niyeu–Valcheta area (Caminos and Llambías, 1984).

If ultramafic rocks were emplaced in a Pampean basement of this density (Table 1) an anomaly of more than 100 mGals could be expected. Most ultramafic belts in suture zones show values between +50 and +120 mGals (Gibb and Thomas, 1976, Kunar et al., 2004, Williams et al., 2006). However, this region does not display anomalies of this magnitude and the seismic profiles also do not suggest the existence of rocks with seismic velocities sufficient to be sourced from ultramafic rocks.

The magnetic survey (Fig. 9) shows scarce magnetic anomalies, with maximum values of +75 nT and minimum values of −75 nT. These data also preclude the existence of mafic–ultramafic rocks in this area and are more consistent with a magnetic source such as the non-magnetic rocks such as Pampean low-grade metamorphic rocks.

4.1.4. Viedma High

Gravity anomalies from the Viedma High (Figs. 7A and 10) vary between 1 and 15 mGal, (Figs. 7A and 10), suggesting a density contrast caused by rocks with similar densities to that which caused the Choele Choel High. The contact between both of these gravimetric highs is defined by NW–SE and NE–SW lineaments that follow narrow belts with steep gravity gradients (Figs 7A, 8 and 10). Unfortunately, there are no seismic profiles located in this area, but outcrops in the nearby Salinas del Gualicho area (Fig. 3) belong to the Nahuel Niyeu Formation (Figs. 3 and 10). Minor outcrops of the Sierra Grande Formation and Gondwana igneous rocks are also present. Drill holes at O'Connor and Elvira (Kaasschieter, 1965) intersected low-grade metamorphic rocks to a depth between 400 and 475 m. (Fig. 7).

The positive gravity anomalies associated with the Viedma High extend northwards (Kostadinoff and Labudía, 1991 and Kostadinoff, 1992) and link with positive gravity anomalies located to the west of Sierras Australes (Figs. 2, 3, 7A and 10). The Algarrobo drill hole, and refraction data near Bahía Blanca (Estancia El Recuerdo and Puerto Belgrano, Bonorino et al, 1987), indicates seismic velocities similar to those that are interpreted to be the source of the Choele Choel High (i.e. low-grade metamorphic rocks of the Las Piedras Metamorphic Complex).

The distribution of positive anomalies in the Viedma High and in the Choele Choel High supports the interpretation that a belt of Pampean rocks extends from the southern part of the Buenos Aires province to northern Patagonia (Figs. 3 and 10).

4.2. Negative anomalies

4.2.1. Neuquén Basin

The Mesozoic Neuquén Basin (Figs 2, 7A and 10) is characterized by gravity lows between −54 mGal and −32 mGal. Seismic data (Fig. 6D) and drill hole information indicate that the sedimentary sequences reach an approximate thickness of 3000 m. Negative gravity anomalies (−41 mGal) near Chelforó represent small depocenters, whose thicknesses decrease to

750 m near Chimpay (Fig. 7A). Magnetic anomalies in this area vary between −125 and +125 nT (Fig. 9) and are attributed to the presence of Fe-oxides in the Cretaceous Neuquén Group (400 m thick) that covers this portion of the basin.

4.2.2. Carapacha Basin

The scarce outcrops of the Permian continental Carapacha Basin and the volcanic rocks near Puelches in La Pampa province (Fig. 4) are coincident with negative gravity anomalies (−40 to −30 mGal: Fig. 7A). The density contrast between these rocks and those of the Pampean basement is relatively low (Table 1 and Fig. 7B), which led to Kostadinoff et al. (2001) to estimate a thickness of 2700 m for this basin. This is substantially more than the 900 m thickness estimated by Melchor (1999). Based on these results, Kostadinoff and Llambías (2002) considered the subsurface extent of the basin to be greater than that suggested its surface extent.

Therefore, the gravimetric minimums of −41, −31 and −40 mGal located northeast of Gobernador Duval, as well as those located west of Cerro Los Viejos and Pichí Mahuida (−41 and −36 mGal), possibly represent an extension of the Carapacha Basin (Figs. 7A, B and 10). In the Carapacha Basin, the Gondwana volcanic rocks unconformably overlying the Paleozoic sedimentary sequences in the Carapacha Basin and are interpreted to contribute to the negative anomalies. The magnetic anomalies (−275, −225 and −125 nT: Fig. 9) are due to the low susceptibility of the Paleozoic sedimentary rocks and the Gondwana acidic volcanic rocks.

4.2.3. Estancia El Caldén Basin

A relatively small negative residual gravity anomaly (−24 mGal: Fig. 7A) is located near the Estancia El Caldén (Kostadinoff et al., 2005), north of the Huincul Fault Zone. A density contrast of −0.2 g/cm^3 between the Pampean basement and the Mesozoic sedimentary units suggests a sedimentary thickness of 1700 m (Figs. 7A and 10). Refraction data in this area (Fig. 6E) indicate a greater than 1000 m thick sedimentary pile. The seismic data suggest velocities consistent with Lower Cretaceous and Upper Tertiary sedimentary successions, which cover the Paleozoic rocks.

4.2.4. Ramos Mexías anomaly

The Ramos Mexías anomaly is part of a continental-scale anomaly (500 km in diameter), located in the south-western part of the North Patagonian Massif (Blitzkow et al., 1994). The Ramos Mexías anomaly corresponds to a large area of several negative gravity anomalies (−46 mGal to −35 mGal, Figs. 7A and 10) located south of the lineament “B) (Fig. 10). Outcrops include Pampean metamorphic rocks and Gondwana intrusive and volcanic rocks. The metamorphic rocks belong to the Nahuel Niyeu Formation and include micaceous and amphibolite schist, marble, and amphibolites. The intrusive rocks (minor tonalite, granodiorite and granite) belong to the Gondwana Navarrete Plutonic Complex. The volcanic rocks (acidic ignimbrite) are part of the Treneta Volcanic Complex (Caminos et al., 2001) and the Triassic volcaniclastic Los Menucos Complex (Cucchi et al., 1999).

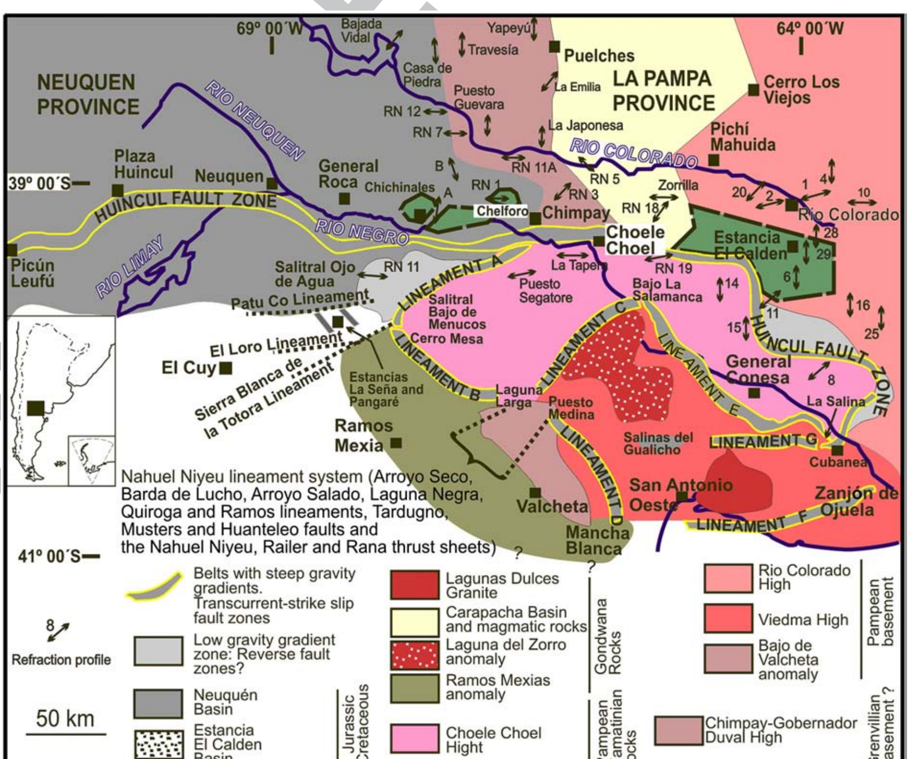


Fig. 10. Distribution of basins, positive areas and lineaments found during this study. Structural lineaments in the Valcheta, Ramos Mexías, and El Cuy areas are related to the lineaments with steep gravity gradients. Locations of refraction shots are displayed.

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

Table 2
Belts of steep gravity gradients

Lineament	Location	Gradient (mGal/km)	Direction	Surface evidence	Related to	Possible age
A	Salitral Bajo de Menucos to Chimpay	1–1.3	SW–NE	Not surface evidence, due to the Tertiary–Quaternary cover.	The continuity of the Sierra Blanca de la Totora, Patú Co and El Loro fault system (200 km long)	The Sierra Blanca de la Totora, Patú Co and El Loro fault system were active during emplacement of the Upper Paleozoic granitic bodies located between these lineaments (Saini-Eidukat et al., in press)
B	Cerro Mesa to Laguna La Larga	1–1.2 in the NW segment. 0.5 in the W–E segment.	NW–SE	A system of topographic lows (Salitral Ojo de Agua, Laguna Larga)	Parallel to the Pangaré Mylonite (Gregori et a., 2000) and Salinas Trapalcó–Laguna Curicó lineament (Ramos and Cortés, 1984. See our Fig. 1 and 2)	The Pangaré Mylonite was active during Upper Paleozoic (Saini-Eidukat et al., in press)
C	Laguna La Larga to Bajo La Salamanca	0.5	SW–NE	Not surficial expression, extensive Tertiary–Quaternary cover.	The continuity of the Nahuel Niyeu lineament system, which is a major structure 25 km wide, 65 km long between the Salinas Trapalcó–Laguna Cuiricó Lineament (Ramos and Cortés, 1984) and the Somoncura Plateau. Include the Arroyo Seco, Barda de Lucho, Arroyo Salado, Laguna Negra, Quiroga and Ramos lineaments, the Tardugno, Musters and Huanteleo faults and the Nahuel Niyeu, Railer and Rana thrust sheets	According to von Gosen (2003) the Nahuel Niyeu, Railer and Rana thrust sheets indicate N–S transport during the Neopaleozoic.
Q1 D	Puesto Medina to Estación Mancha Blanca	1	NW–SE	Parallel to the Salinas Trapalcó–Laguna Curicó lineament (Ramos and Cortés, 1984. See our Fig. 1 and 2)	Possibly related to the El Jaguelito Fault zone (Ramos, 1975. See our Fig. 11)	El Jaguelito Fault zone and associated minor mylonitic belts were active during the Upper Paleozoic (Giacosa, 2001)
E	Bajo La Salamanca to La Salina	0.5	NW–SE and E–W	The Rio Negro follows approximately the lineament direction	Parallel to the Salinas Trapalcó–Laguna Curicó lineament (Ramos and Cortés, 1984)	Since this lineament shows a strike and development similar to lineament D it is believed that both were generated during the same episode.
F	San Antonio Oeste to Zanjón de Oyuela	2	W–E and ENE direction	Not surficial expression was recognized	?	?
G	La Salina to Salinas del Gualicho	2	W–E	Not topographic features represent this lineament.	Located inside of the Viedma High	Possibly a continuation of the Huincul Fault zone ?

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

4.2.5. Lagunas Dulces anomaly

The Lagunas Dulces anomaly is a negative gravity anomaly (−20 mGal) that is located north-eastwards of San Antonio Oeste (Figs. 7A and 10). This anomaly is interpreted to be caused by the Lagunas Dulces Granite (Kostadinoff, 1992). A drill hole at this locality intersected granitic rocks (249±10 Ma: Kaasschieter, 1965) at a depth of 370 m. Because the geometry and magnitude of this anomaly is similar to those coincident with outcrops of the Gondwana Navarrete Granodiorite, we interpret the Lagunas Dulces anomaly to be caused by intrusion of Gondwana granitic bodies in the Pampean basement.

4.2.6. Bajo de Valcheta anomaly

The Bajo de Valcheta anomaly is a negative anomaly of the order of −10 mGal, located between the Viedma High and the Ramos Mexías anomaly. The area is coincident with outcrops of the low-grade metamorphic rocks of the Nahuel Niyeu Formation (Figs. 7A, B and 10). According to the model in Fig. 7B a density of 2.65 g/cm^3 is required to satisfy the observed anomalies. No significant magnetic anomalies (Fig. 9) can be recognized at this location.

4.2.7. Laguna del Zorro anomaly

The Laguna del Zorro gravity anomaly (Figs. 7A and 10) is located to the north-west of the Viedma High and is bounded by lineament “C” (Fig. 10). The geometry and magnitude of the anomaly is similar to the Lagunas Dulces anomaly and is therefore interpreted to be sourced from the same or similar Gondwana intrusive body.

4.3. Belts of steep gravity gradients

In order to validate the continuity of the Huincul Fault zone and other structural lineaments proposed by Turner and Baldis (1978), we focused on areas with steep gravity gradients in the gravity anomaly map. Such steep gradients are usually interpreted as representing fault structures (Nettleton, 1976), boundaries of rocks with contrasting petrophysical characteristics or sutures (Gibb and Thomas, 1976, Wellman 1978, Coward and Fairhead 1980, Gibb et al. 1983). Differences in density or thickness between blocks are often responsible for steep gradients (Gibb and Thomas, 1976, Thomas, 1983, Kunar et al. 2004, Williams et al., 2006). Values between 0.5 and 2 mGal/km, were obtained using the gradient and second derivate operator. A 3D image generated using Surfer 8™ (Fig. 8B), show several lineaments defined by belts with steep gravity gradients.

Table 2 indicates the name, location, gradient, any surface evidence and possible age of each lineament, while their location is shown in Fig. 10. Three main lineament orientations directions can be recognized: lineaments A and C are NE–SW trending; lineaments B, D and E are NW–SE trending; and lineaments F, G and the Huincul Fault zone are E–W trending. The E–W lineaments exhibit more complex geometries than the other lineaments. Most lineaments form the boundary of the Choele Choel High (e.g. A, B, C, E and the Huincul Fault zone).

4.3.1. Huincul Fault zone

Because the Huincul Fault zone (Kostadinoff et al., 2005) crops out in the Neuquén Basin (Windhausen, 1914 and Keidel,

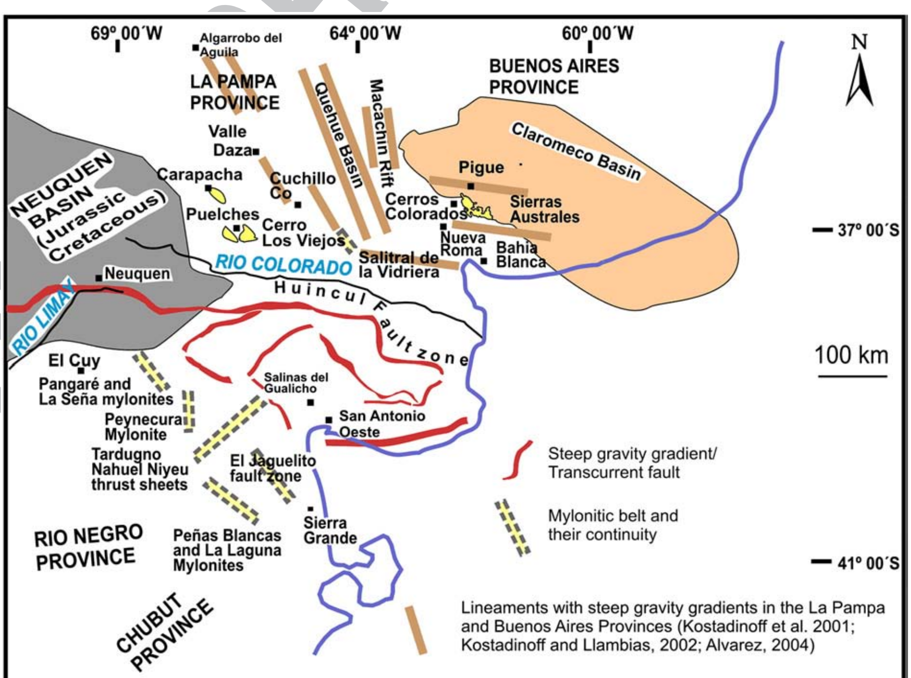


Fig. 11. Lineaments (this study, Kostadinoff et al., 2001, Kostadinoff and Llambías, 2002 and Alvarez, 2004) and mylonitic belts detected in northern Patagonia, Buenos Aires and La Pampa provinces.

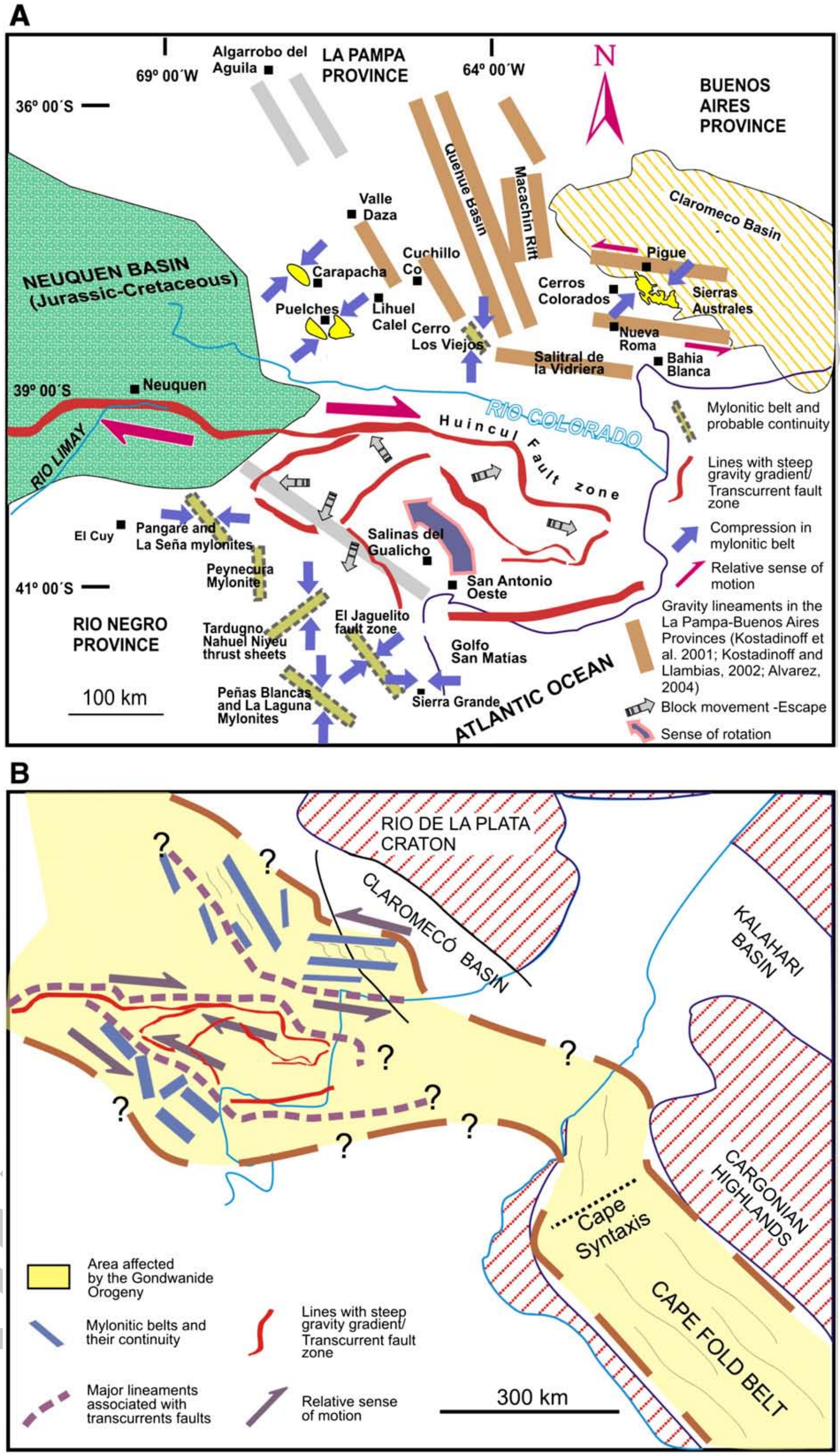


Fig. 12. A) Lineaments and mylonitic belts in northern Patagonia. Directions of compression in mylonitic belts, block movements and escape, as well as, relative sense of motion in the Huincul Fault zones and the proposed sense of rotation south of this fault zone are displayed. B) Possible configuration of the Gondwanide Orogenic belt in northern Patagonia–South Africa area. Deformation of the Cape and Claromecó basins is evidence of the effect of such orogeny. In the North Patagonia Massif the deformation is less obvious but mylonitic belts and foliated granites show the existence of such orogeny, although its effects seem to be more areally extended.

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

1925), its configuration and kinematics are relatively well constrained. The Huincul Fault Zone displays dextral strike-slip movement (Orchuela and Ploszkiewicz, 1984) and a zig-zag along strike pattern (Figs. 2 and 10). This pattern suggests that both transtensional and transpressional conditions occurred during fault movement, resulting in the contemporaneous development of positive and negative flower structures. This fault system was active from Upper Paleozoic–Triassic times, as recorded by continental depocenters associated with the transtensional subsidence (Vergani et al. 1995).

Its eastwards continuity was suggested by Turner and Baldis (1978), and established by Orchuela and Ploszkiewicz (1984) based on interpretation of seismic reflection data. The high gravimetric gradients between Neuquén and Cubanea (Figs. 7, 8B and 10) support the continuity of the Huincul Fault Zone until 63° 40¢ [illegible] with maximum gr[illegible]nts (2 [illegible]Gal/km) between the Neuquén Basin and 64° 45¢ W–39° 20¢ [illegible].

The section between Neuquén and Chimpay shows a smooth releasing bend (Fi[illegible]0), t[illegible]hanges to a restraining bend in the Chimpay [illegible] 40¢ W section. The gravity anomalies are discontinuous along the fault zone. In the area between Chimpay and Cubanea, the differences in magnitude of the anomaly between the Choele Choel High and the Carapacha Basin and the Río Colorado High mark the trace of this fault zone. In the section between Chimpay and Neuquén, such differences in the anomalies are less evident, but high gravimetric gradients (2 mGal/km) are interpreted to reflect the location of the fault zone.

Magnetic anomalies are diffusely coincident with the interpreted fault zone between 5 and 10 km north of Chichinales and Choele Choel. These anomalies are low-amplitude (175 to 75 nT, Fig. 9) and are interpreted to be related to the Albian–Coniacian red beds of the Neuquén Group, which contain abundant Fe-oxides (hematite). The sediments have a magnetic susceptibility of 0.006500 SI (Telford et al., 1990), which is sufficient to explain the magnitude of the magnetic anomalies. These low-magnitude anomalies do not compared magnetic anomalies typically observed in sutures zones because suture zones are generally composed by serpentinite zones associated with sheared peridotites, which have a magnetic response >500 nT (Ferraccioli et al., 2002). The Huincul Fault zone is therefore unlikely to be a suture.

In the Neuquén–Chichinales section (Fig. 10) the Neuquén Group is 1000 m thick, but in the cliffs located south of the Rio Negro, only the upper section of this unit crop outs. In contrast, the area north of the fault zone, Upper Cretaceous–Lower Tertiary marine Malargue Group crop out, suggesting more than 500 m of vertical displacement across a fault zone.

Due to the outline of the Huincul Fault Zone, the section between Plaza Huincul and Picún Leufú (Fig. 10) and between Neuquén and Chimpay represent domains of dextral transpressive shear (Orchuela and Ploszkiewicz, 1984), where basement rocks are exposed in [illegible] fault zone. In the section between Chimpay and 64° 15¢ W, deformation appears to be transtensional based on the existence of small depocenters associated to the fault zone.

5. Mylonitic belts and lineaments with steep gravimetric and high magnetic gradients in northern Patagonia, southern La Pampa and Buenos Aires provinces

Northern Patagonia is characterized by the presence of several mylonitic belts and regional structural lineaments, whose geometries, deformational mechanisms and age mostly remains unclear (Fig. 11). The better-known of these lineaments and mylonites include:

a) Pangaré and La Seña mylonites (Gregori et al., 2000), are formed by two belts, each 1 km wide, 15 km long, and comprising granitic augen-mylonites, protomylonites, mylonites and ultramylonites, (Figs 10, 11 and 12A) with strikes between 310° and 330°. They exhibit sinistral movement associated with an east–west compression.
b) Peynecura mylonitic belt (Llambías et al., 2002) is more than 500 m wide, 15 km long, and has a NNW–SSE strike (Fig. 11). The deformation is interpreted to have occurred during the Early Triassic because is related to foliated granites of such age. No information about strain orientation is available.
c) The El Jaguelito Fault zone is a 50 km long NW–SE dextral lineament that appears in the eastern area of the North Patagonian Massif (Fig. 11). According to Ramos and Cortés (1984), deformation occurred during Upper Paleozoic times.
d) Peñas Blancas and La Laguna mylonites are described by Giacosa (1996). They are 10 km long, and are temporal related to the foliated Permian-aged Peñas Blancas and La Laguna Granites. Four more NW–SE mylonitic belts were recognized during regional mapping in this area, but information on strain orientation is unavailable. The timing of deformation is interpreted to be Gondwanan because the foliated granites were intruded at the same time as mylonitization occur.
e) The Nahuel Niyeu lineament system is a major structure that is 25 km wide, and extends for 65 km long (Figs. 10 and 11) between the Salinas Trapalcó–Laguna Curicó Lineament (Figs. 1, 2 and 12A) and the Somoncura Plateau (Fig. 2). Nahuel Niyeu lineament includes the Arroyo Seco, Barda de Lucho, Arroyo Salado, Laguna Negra, Quiroga and Ramos lineaments, the Tardugno, Musters and Huanteleo faults and the Nahuel Niyeu, Railer and Rana thrust sheets (Fig. 10).

In the La Pampa province, a mylonitic belt was described in Cerro de los Viejos (Figs. 11 and 12A) by Tickyj et al. (1997). A further four belts of steep gravity gradients which were interpreted as major structures were described by Kostadinoff et al. (2001). These four belts include:

a) The Quehué lineaments is a 350 km long, 15 km wide. It is defined in the gravity data by a 2 mGal/km gradient which defines a structure interpreted to represent the boundaries of the Triassic Quehué basin.
b) The Valle Daza-Cuchillo Có lineament is a 310–320° trending belt that is 100 km long and characterised by a steep gradient in gravimetry data. This lineament is interpreted to represent the western boundary of the Rio Colorado High (Figs. 11 and 12A).

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

c) The Cerro los Viejos lineament extends in a NW-direction for more than 100 km from Cerro Los Viejos and is possibly related to the Cerro Los Viejos mylonite. According to Kostadinoff and Llambías (2002), the Cerro los Viejos lineament represents the contact between the Permian Carapacha Basin and the Río Colorado High. This lineament and its associated steep gravity gradient disappears in the central part of the La Pampa province, but is identified near Algarrobo del Aguila (Fig. 11) as a 50 km long, 15 km wide lineament with steep gravity gradient. This NW-trending structure is considered to be the boundary of a Triassic basin (Kostadinoff and Llambías, 2002).

d) The Macachín Rift includes Paleozoic and Mesozoic sedimentary sequences deposited in a NNW–SSE extensional basin (Figs. 11 and 12A). Outcrops of igneous and sedimentary Gondwanan rocks in the central part of the La Pampa province (Figs 2 and 4) follow WNW or NW trends, which suggest structural control.

In the Buenos Aires Province strike-slip faults located north and south have been used to explain the structure of the Sierras Australes. For example, Newton and Cingolani (1990) showed a series of WNW–ESE trending sinistral strike-slip faults near Pigue and Cerros Colorados (Figs. 11 and 12A), which are evident in gravity data (Alvarez, 2004). In the Bahía Blanca area, Bonorino et al. (1987) showed the occurrence of several lineaments with steep gravity gradients south of Sierras Australes. Lineaments of importance include the Salitral de la Vidriera and Nueva Roma belts, which are strike-slip fault zones longer than 100 km in strike extent (Fig. 11).

6. Gondwana deformation in the Neuquén Basin, northern Patagonia and southern La Pampa and Buenos Aires provinces

Windhausen (1914), Keidel (1925) and Groeber (1929) described NE–SW structures transverse to the N–S Andean Orogeny in the Neuquén Basin (Figs. 11 and 12A). According to these authors, as well as Herrero Ducloux (1946) and De Ferraris (1947) the stratigraphic and structural evidences suggest folding during the Cenomanian or the Middle Jurassic. They observed that the structures mimic the northwestern and northern border of the North Patagonian Massif and that they possibly formed during NW- and N-directed lateral translation of the massif. These structures were grouped in the “Dorsal de Huincul” (Huincul Fault zone) by De Ferraris (1947).

In the North Patagonian Massif, the Gondwana deformation is recorded by the Pangaré and La Seña mylonites. Clearly defined δ and σ type porphyroclasts of K-feldspar, and shaped lenses of Qz–K-feldspar, support sinistral movement. These belts and the associated foliated granite (Gregori et al., 2000) indicate maximum compression (σ_1) in a WNW–ESE direction (Fig. 12A) during Middle to Upper Triassic (Saini-Eidukat et al., in press).

In the El Jaguelito Fault zone, the fault pattern suggests a dextral transcurrence along N 310° (Fig. 12A) during Upper Paleozoic times (Ramos and Cortés, 1984). SE, S and SW vergence occurred along the Nahuel Niyeu lineament system (Fig. 12A), each of which was related to three phases of deformation, with principle shortening directions in NE–SW, NW–SE and E–W directions during Permo-Triassic times (von Gosen, 2003).

In the Sierra Grande area, the Pampean El Jaguelito Formation contains evidence which supports a D1 event that was generated by NW–SE or E–W shortening (Giacosa and Paredes, 2001, von Gosen, 2002). In the same area, the Famatinian Sierra Grande Formation is folded around open synclines and anticlines that have N–S trending axial traces (Fig. 12A). The Permian Laguna Medina granite intrudes the Sierra Grande Formation and records a ductile E–W shortening deformation event, which was coincident with deformation of the Sierra Grande Formation (Rossello et al., 1997, von Gosen, 2002).

Transport directions from NE to SW during the Gondwana deformation was accommodated along mylonites within the Peñas Blancas and La Laguna Granites (Giacosa, 2001, von Gosen, 2002).

In the North Patagonian Massif, the Sierra Grande Formation, the Laguna Medina Granite and foliated granites and mylonites in the Estancias La Seña and Pangaré area all indicate shortening in a WNW–ESE or E–W direction (Fig. 12A). The mylonites in the Peñas Blancas and La Laguna Granites and thrust sheets and faults in the Nahuel Niyeu area are related to a N–S or SW–NE shortening (Fig. 12A) (Giacosa, 2001, von Gosen, 2002).

In the La Pampa Province, the Carapacha Basin (Figs. 4, 11 and 12A) exhibits a NW–SE elongation, suggesting basin development occurred during NE–SW direction extension. Folding of the sedimentary successions and inversion in the Carapacha Basin (Melchor, 1999) and mylonitization of the Cerro de los Viejos granite (Tickyj et al., 1997) dated as Late Permian (254±2 Ma), suggests that both areas were affected by the same deformational phase (Fig. 12A) related to a NE–SW shortening.

In the Sierras Australes of Buenos Aires Province, the Pillahuincó Group (Carboniferous-Permian) was deformed (Fig. 12A) between the late Early Permian and the early Late Permian (Tomezzoli and Vilas, 1996). Deformation generated a sigmoidally-shaped mountain chain. Folding and overthrusting occurred during NE vergence (von Gosen et al., 1990). This deformation was related to sinistral transpressive deformation (Sellés Martinez, 1989) along the WNW–ESE Pigué transcurrent fault system (Alvarez, 2004) and the Salitral de la Vidriera and Nueva Roma transcurrent fault systems (Bonorino et al., 1987). The deformation was interpreted to be related to transpressive movement of the “Patagonian block” relative to the South American craton during Permo-Triassic time (Martinez, 1980), although little supporting evidence was provided. Sellés Martínez (1989) considered the deformation in Sierras Australes to be due to a transpressive regime between the Patagonian block and the South American craton during the Late Permian oblique subduction.

Detailed structural studies in the Sierras Australes define a sigmoidal belt, with fold trends rotating >60° clockwise, from WNW to NNW, a configuration attributable to dextral transpression (Cobbold et al., 1986, 1991, 1992). Inferred directions of principle shortening are oblique to the orogenic belt, and to

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

the convergent southern margin of Gondwana and are interpreted to result from oblique (dextral) subduction beneath an Andean-type margin (Cobbold et al., 1992, Craddock et al., 1998).

Consequently, the sedimentary basins, the emplacement of the Gondwana intrusive and volcanic rocks and the regional structure north of the Colorado and Negro rivers are related to a first SW–NE extension (Fig. 4), which later switched to a shortening regime in a NE–SW or N–S direction (Fig. 12A).

In their structural analysis of northern Patagonia, Turner and Baldis (1978) identified several NW–SE lineaments in the area between Bajo del Gualicho and Golfo San Matías (Fig. 2). They suggested variable compressive stresses in the North Patagonian Massif including: west-shortening directed (Río Limay area); northeast-directed shortening (Salinas del Gualicho); east-directed shortening (Sierra Grande); and southwest-directed shortening (El Cuy). The variation in stress directions is attributed to counterclockwise rotation of the North Patagonian Massif (Fig. 12A).

7. Deformation in the southern area of the Gondwana supercontinent

The first detailed reconstruction of the relative position of Africa and South America during the Upper Paleozoic was given by du Toit (1927). The continuity of an orogenic system was extended from South America to Australia, passing just south of the Permo-Triassic fold belts, introducing the name of Samfrau Orogenic Zone (du Toit, 1937). This belt is nearly equivalent to what we understand today as the Gondwanide Orogenic Belt (du Toit, 1937).

In the South African segment, the arrangement of the Gondwanide Orogenic Belt and the associated basins is strongly conditioned by the configuration of older basements blocks (Kaapvaal, ≥2.5 Ga, Namaqua-Natal, ≈1 Ga and Gariep, Saldania and Mozambique, 1–0.5 Ga). The Ordovician–Devonian Cape Basin follows a main W–E trend along the Saldania province with branches to the NW and NE. The Cape Fold Belt includes southern and western tectonic domains (Söhnge, 1983), separated by the Cape Syntaxis (Fig. 12b), across which the structural strike, and the intensity of deformation changes markedly (de Beer, 1995). The southern domain extends from the eastern margin of the Cape Syntaxis to Port Elizabeth and is characterized by east–west-trending, north-verging structures including bedding-parallel thrusts and north-verging folds (Fig. 12B). No evidence for dextral shearing was found in this domain.

In the western domain, strata is mildly deformed (de Beer, 1992). Folds and faults trend northwest to north (de Beer, 1990). North-trending slickensides developed on thrust planes (Ransome and de Wit, 1992) and stretching lineations (Cobbold et al., 1992) indicate a component of strike-parallel displacement. The pattern of folds, faults and lineations are consistent with overall dextral strike-slip deformation (Cobbold et al., 1992). The Cape Syntaxis is a northeast-trending structural domain that separates the southern and western domains (de Beer, 1995). Based on a reconnaissance of the structure of the syntaxis and adjacent domains, Ransome and de Wit (1992) proposed a model in which the continental crust to the west of Cape Syntaxis was rotated clockwise during syntaxis formation, while crust immediately east is rotated counter-clockwise.

In the Malvinas (Falkland) Islands, Late Permian fold and thrust belt structures form the eastward continuation of the Cape Fold Belt when restored into a pre-Gondwana break-up configuration. Detailed structural studies by Curtis and Hyam (1998) and Hyam (1998) suggest that these structures developed in a complex strain system of combined NW–SE shortening and dextral shear.

In Antarctica, the Gondwanide Orogen extends through the Ellsworth–Whitmore Mountain block and the Pensacola Mountains (Curtis and Storey, 1996). During Gondwanide orogenesis the Ellsworth–Whitmore Mountain block is assumed to have occupied a site intermediate between the more easterly Falkland Islands and the more westerly Pensacola Mountains (Curtis and Storey, 1996). Structural analyses (fold orientation, shortening directions and strain partitioning) indicate contemporaneous development of gently plunging foreland-verging folds and asymmetric, steeply plunging folds symptomatic of deformation within a highly oblique dextral transpressive belt (Curtis, 1997, 1998, Craddock et al., 1998).

Dextral transpressional structures are evident throughout much of the Gondwanide Belt, suggesting a component of dextral transpressional during the evolution of this orogenic belt. Johnston (2000) indicated that the east–west-trending domain of the Cape Fold Belt ends to the west and east against the northwest-trending South American and Antarctic portions of the Gondwanide Orogen respectively.

8. Tectonic model

The diverse shortening directions and lateral crustal translations during Gondwana time north and south of the interpreted boundary between northern Patagonia and Gondwana South America cannot be explained as the result of homogeneous stress regime (i.e. NE–SW compression due to the subduction and collision of Patagonia with the southern margin of Gondwana South America) as speculated by Ramos (1984), and von Gosen (2002, 2003).

All lineaments plotted in Fig. 11 (those both related and unrelated to mylonites, and the belts with steep gravity and magnetic gradients, presumably active during Gondwana times) suggest a lineament network that defines a block system (Fig. 12A). This collage of continental crustal blocks and its movement was the result of a tectonic event that produced crustal fragmentation. The geometry of individual blocks controlled the block movement and therefore the development of mylonite belts and other lineaments. In order to explain the variable stress regime in which zone of compressional and extensional tectonism were active at the same time over such a large area, we require movement of crustal blocks along arcuate strike-slip faults (Fig. 12A).

This style of deformation is common during collisional orogeny, where frontal zones are deformed during indentor tectonics, where the lateral terminations of the indentor involve extensive escape tectonics (Ratschbacher et al., 1991). The size and shape of the continental fragments involved, the orientation

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

of the indentor, and the collision vector, influence the extent and geometry of indentation and later escape.

Modern examples of large-scale indentation-escape orogens are found in the Himalaya-Alpine belt. These models include the collision of the Arabian and the European plates (west-directed escape) and the east- and southeast-directed escape of southeast Asia following the collision of India and Asia (Tapponnier and Molnar, 1976). The transcurrent shear zones separating elongate crustal slices are the most important large-scale structural features in these Himalaya–Alpine models.

Indentation-escape tectonics is widely observed and accepted in younger orogens, but has not been recognized to the same extent in older mountain belts, probably because the structures associated with such a tectonic regime are less obvious. In addition, subsequent orogenic events may obscure the presence of an ancient indentation-escape regime (Ratschbacher et al., 1991).

Several examples of Precambrian indentation-escape tectonics have been described. In southern Africa, the proto-Kalahari craton acted as a southwest-directed indenter into juvenile Mesoproterozoic island-arc terranes at ca. 1100 Ma (Jacobs et al., 1993). The associated escape tectonics regime in the orogen is shown by extensive craton-parallel ductile shear zones and the development of pull-apart basins in the preserved African foreland (Koras–Sinclair basins). Other example of indenter-escape tectonic has been reported in Australia, where the Yilgara craton indented the Pilbara–Gawler craton during the late Paleoproterozoic Capricorn orogeny (Krapez, 1999). Another example is the East African–Antarctic orogen, which resulted from the collision of various parts of proto-East and West Gondwana during late Neoproterozoic–early Paleozoic time (between 650 and 500 Ma). The southern part of this Himalayan-type orogen can be interpreted in terms of a lateral-escape tectonic model. Small microplates (the Falkland, Ellsworth–Haag, and Filchner blocks) probably represent shear-zone-bounded blocks produced by tectonic translation during lateral escape, similar to those currently evolving in Southeast Asia.

Assuming a model of indentation-escape tectonics for northern Patagonia, the belts with steep gravity gradients described in this study represent transcurrent shear zones separating shear-zone-bounded blocks (Figs. 11 and 12A). The block situated between lineaments C, D and E has possibly acted as a northwest-directed indenter associated with west-directed movements of the area located south of the Huincul Fault zone. Several small blocks were displaced west and southwest, possibly the western sector of the Choele Choel High and the areas located west of the line A and southwest of line B, as recorded in the La Seña–Pangaré mylonites and Nahuel Niyeu system (Fig. 12A).

The eastern sector of the Choele Choel High, between the Huincul Fault zone and lineament E was displaced to the east and southeast during lateral escape. In areas of transpression, such as along the Huincul Fault Zone between Estancia El Caldén and Chimpay (Fig. 10), rocks were faulted upwards to form positive flower structures. Such a configuration can explain the uplift of the Choele Choel High against the Carapacha Basin and accounts for the change of detritus composition as detected in the Carapacha and Claromecó Basins (Rossello et al, 1997, Melchor, 1999).

It seems probable that some blocks in the North Patagonian Massif, located south of the Huincul Fault Zone, rotated counterclockwise during Permo-Triassic time (Fig. 12A). It is doubtful that the deformation can be explained in terms of the collision of two major crustal blocks, principally because there is no conclusive evidence for such a collision.

The development of the Gondwanide deformation in northern Patagonia–Sierras Australes–La Pampa province in a location far from the active convergent margin of Gondwana is attributable to two factors: a) dextral margin-parallel translation of a crustal block or blocks (Fig. 12A and B) outboard of the Gondwanide Orogen; and b) the oblique orientation of this area relative to the east–west trend (present coordinates) of the orogen in the Cape Fold Belt, as shown in Fig. 12B.

Coincidences in timing of deformation and the orientation of principal stress directions, point to an evolutionary history that is similar to other portions of the Gondwanide Orogen (de Wit and Ransome, 1992; Cobbold et al., 1991, Vaughan and Pankhurst, 2008).

In the southern Canadian Rocky Mountain fold and thrust belt, Late Cretaceous and Tertiary deformation developed ~1500 km inboard of the active convergent margin (McMechan and Thompson, 1989). Oblique (dextral) subduction of oceanic plates beneath western North America resulted in the development of major dextral strike-slip faults within the overriding North American crust. The development of this fold and thrust belt 1500 km inboard of the cordilleran margin in response to oblique subduction-driven, margin-parallel dextral translation was considered as an analogue for development of the Cape Fold Belt (Johnston, 2000). According to the evidence presented here, this model can also be applied to northern Patagonia. However, the relatively extensive width of this active margin is at present not fully understood.

9. Conclusions

North–South belts of Pampean and Famatinian rocks that cross the supposed boundary between the northern Patagonia and central Argentina regions support the presence of a common continental crust in both areas. No geological or geophysical evidences for oceanic crust formed by mafic–ultramafic rocks between both areas have been identified. The gravity and magnetic anomalies over the supposed boundary are incompatible with a suture composed of such rocks.

The continental crust in the studied area was sliced by displacements along the dextral Huincul Fault Zone and several minor lineaments that represent strike-slip faults along the boundaries of several continental blocks. South of the Huincul Fault Zone, the indentation of these blocks, related to the translation and simultaneous counterclockwise rotation along a NW-direction produced escape of minor slices in W, SW, E, SE, and N directions. Such movements are recorded in Gondwana rocks and mylonitic belts around northern Patagonia.

Transpression in the northern part of the massif possibly produced positive flower structures, e.g.: the Choele Choel High or those recognized in the Neuquén Basin.

The balance of evidence suggests that the Gondwanide Orogeny in the northern Patagonia area is due to the transtensive–transpressive deformation. The dextral strike-slip component detected in the northern Patagonia–Sierras Australes, Cape Fold Belt (Africa), and in the Ellsworth Whitmore Mountains block (Antarctica), may reflect margin-parallel strike-slip movements induced by oblique subduction (Cobbold et al., 1991, 1992) beneath the convergent southern margin of Gondwana.

Acknowledgements

This study is part of the research projects Prospección geofísica de la Provincia de Rio Negro (24/H061), Ciclos tectomagmáticos de la Republica Argentina (24/H060) granted by Universidad Nacional del Sur and Análisis de la configuración y evolución geológico–geofísica del sector oriental de la Comarca Nordpatagónica (546) by ANPCYT-UNS (Agencia Nacional de Promoción Científica y Tecnológica.).

We would like to thank Emiliano Santiago, Daniel Lafont, María Varela for helping during field trips. Many thanks to Guillermina Alvarez for assistance during calculation of the magnetic anomalies and construction of the magnetic anomaly map. Many thanks to Anthony Tankard who pointed out the similarities between our steep gravity gradient lineaments and the magnetic lineaments found in the marine platform. We are deeply grateful for the comments and suggestions made by the reviewers H. Williams, Monash University, Australia and R. Hackney, Uni Kiel, Germany who made a detailed review of the manuscript improving considerably the quality of the manuscript. Peter Betts, Monash University and Gondwana Research editor is profoundly acknowledged for the review of the manuscript style and language, as well as manuscript handling.

References

Alvarez, G.T., 2004. Cuencas paleozoicas asociadas a la prolongación norte del sistema de Sierras de Ventana, provincial de Buenos Aires. Ph.D. thesis, Universidad del Sur, Bahía Blanca, Argentina.

Blitzkow, D., Fairhead, J.D., Lobianco, M.C., 1994. Attempt for a gravimetric geoid in South America. In: 18 Reunión Científica de Geofísica y Geodesia. Programa de sesiones cientificas/resúmen. La Plata, Asociación Argentina de Geofísicos y Geodestas, pp. 70–71.

Bonorino, A.G., Kostadinoff, J., Schillizzi, R., 1987. Geofísica y geología del sector noroccidental de la cuenca del Colorado. Provincia de Buenos Aires. Geoacta 17, 167–177.

Buggisch, W., 1987. Stratigraphy and very low grade metamorphism of the Sierras Australes de la Provincia de Buenos Aires (Argentina) and implications in Gondwana correlation. Zentralblatt für Geologie und Paläontologie I 819–837.

Cabaleiro, A., Cazau, L., Lasalle, D., Penna, E., Robles, D., 2002. Los reservorios de la Formación Centenario. In: Schiuma, M., Hinterwinner, G., Vergani, G. (Eds.), Simposio de Rocas reservorio de las cuencas productivas de la Argentina. 5to Congreso de Exploración y Desarrollo de Hidrocarburos, Mar del Plata, pp. 407–426.

Caminos, R., Llambias, E.J., 1984. El Basamento Cristalino. 9 Congreso Geológico Argentino. (San Carlos de Bariloche). Relatorio 1, 37–63.

Caminos, R., Chernicoff, C.J., Fauqué, L., Franchi, M., Espejo, P., 2001. Geología y recursos naturales de la Hoja 4166-I, Valcheta, Río Negro. Boletín, vol. 310. SEGEMAR, Buenos Aires, p. 132.

Chernicoff, J., Zappettini, E., 2004a. Geología sólida y delimitación de terrenos en la región centro-austral Argentina: Evidencias geofísicas. Revista Geológica de Chile 30, 299–316.

Chernicoff, J., Zapettini, E., 2004b. Geophysical evidence for terrane boundaries in South-Central Argentina. Gondwana Research 7, 1105–1116.

Cobbold, P.R., Massabie, A.C., Rossello, E.A., 1986. Hercynian wrenching and thrusting in the Sierras Australes Foldbelt, Argentina. Hercynica 2, 135–148.

Cobbold, P.R., Gapais, D., Rossello, E.A., 1991. Partitioning of transpressive motions within a sigmoidal foldbelt: the Variscan Sierras Australes, Argentina. Journal of Structural Geology 13, 743–758.

Cobbold, P.R., Gapais, D., Rossello, E.A., Milani, E.J., Szatmari, P., 1992. Permo-Triassic intracontinental deformation in SW Gondwana. In: de Wit, M.J., Ransome, I.G.D. (Eds.), Inversion Tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa. Balkema Publishers, Rotterdam, pp. 23–26.

Coward, M.P., Fairhead, J.D., 1980. Gravity and structural evidences for the deep structure of the Limpopo belt, South Africa. Tectonophysics, 68, 31–43.

Craddock, J.P., McGillion, M.S., Webers, G.F., Yoshida, M., 1998. Strain analysis across the Ventana-Ellsworth fold and thrust belt (extended abstract). Journal of African Earth Science. 27, 49–50.

Cucchi, R.J., Busteros, A., Lema, H., Dalponte, M., Espejo, P., 1999. Geología y recursos naturales de la Hoja 4169-II, Los Menucos, Río Negro. Boletín, vol. 265. SEGEMAR, Buenos Aires, p. 110.

Curtis, M.L., 1997. Gondwanian age dextral transpression and spatial kinematic partitioning within the Heritage Range, Ellsworth Mountains, West Antarctica. Tectonics 16, 172–181.

Curtis, M.L., 1998. Development of kinematic partitioning within a pure-shear dominated dextral transpression zone: the southern Ellsworth Mountains, Antarctica. In: Holdsworth, R.E., Strachan, R.A., Dewey, J.F. (Eds.), Continental Transpressional and Transtensional Tectonics. Geological Society of LondonSpecial Publication, vol. 135, pp. 289–306.

Curtis, M.L., Hyam, D.M., 1998. Late Palæozoic to Mesozoic structural evolution of the Falkland Islands: a displaced segment of the Cape Fold Belt. Journal of the Geological Society 155, 115–129.

Curtis, M.L., Storey, B.C., 1996. A review of geological constraints on the pre-break-up position of the Ellsworth Mountains within Gondwana: implications for Weddell Sea evolution. In: Storey, B.C., King, E.C., Livermore, R.A. (Eds.), Weddell Sea Tectonics and Gondwana Break-up. Special Publication, vol. 108. Geological Society of London, pp. 11–30.

Dalmayrac, B., Laubacher, G., Marocco, R., Martinez, C., Tomasi, P., 1980. La chaine hercynienne d' Amerique du Sud. Structure et evolution d'un orogene intracratonique. Sonderdruck aus der Geologische Rundschau 69, 1–21.

Dalziel, I.W.D., Garrett, S.W., Grunow, A.M., Pankhurst, R.J., Storey, B.C., Vennum, W.R., 1987. The Ellsworth–Whitmore crustal block: its role in the tectonic evolution of West Antarctica. In: McKenzie, G.D. (Ed.), Gondwana Six: Structure, Tectonics, and Geophysics, Geophysical Monograph, vol. 40. American Geophysical Union, Washington, pp. 173–182.

Davidson, J., Mpodozis, C., Godoy, E., Hervé, F., Pankhurst, R., Brook, M., 1987. Late Paleozoic accretionary complexes on the Gondwana margin of southern Chile: Evidence from the Chonos Archipielago. In: McKenzie, G.D. (Ed.), Gondwana Six: Structure, Tectonics, and Geophysics. Geophysical Monograph, vol. 40. American Geophysical Union, Washington, pp. 221–227.

de Beer, C.H., 1990. Simultaneous folding in the Western and Southern branches of the Cape Fold Belt. South African Journal of Geology. 93, 583–591.

de Beer, C.H., 1992. Structural evolution of the Cape Fold Belt syntaxis and its influence on syntectonic sedimentation in the SW Daroo Basin. In: de Wit, M.J., Ransome, I.G.D. (Eds.), Inversion Tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa. Balkema Publishers, Rotterdam, pp. 197–206.

de Beer, C.H., 1995. Fold interference from simultaneous shortening in different directions: the Cape Fold Belt syntaxis. Journal of African Earth Sciences 21, 157–169.

De Ferraris, C., 1947. Edad del arco o dorsal antigua del Neuquén oriental, de acuerdo con la estratigrafía de la zona inmediata. Revista de la Asociación Geológica Argentina 2, 256–283.

Delpino, S., Ferracutti, G., Kostadinoff, J., Bjerg, E., 2005. La prolongación austral de las Sierras Pampeanas en la provincial de La Pampa. Evidencias

Please cite this article as: Gregori, D.A., et al., Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina, Gondwana Research (2008), doi:10.1016/j.gr.2008.04.005

geológicas y geofísicas. Revista de la Asociación Geológica Argentina 60, 535–551.

de Wit, M.J., Ransome, I.G.D., 1992. Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa. Balkema, Rotterdam, p. 269.

Dickerson, P.W., 2004. Pampean Orogen: an intraplate component of Early Paleozoic deformation. Gondwana Research 7, 115–124.

du Toit, A.L., 1927. A geological comparison of South America with South Africa. With a paleontological contribution by F.R. Cowper Red. Carnegie Institute, Washington, p. 158.

du Toit, A.L., 1937. Our Wandering Continents. Oliver and Boyd, Edinburgh, p. 366.

Ferraccioli, F., Bozzo, E., Capponi, G., 2002. Aeromagnetic and gravity anomaly constraints for an early Paleozoic subduction system of Victoria Land, Antarctica. Geophysical Research Letters 29, 10–13.

Giacosa, R., 1996. Zonas de cizalla frágil-dúctil en el sector oriental del Macizo Nordpatagónico. 13 Congreso Geológico Argentino (Buenos Aires). Actas 2, 395.

Giacosa, R.E., 1997. Geología y petrología de las rocas pre-cretácicas de la región de Sierra Pailemán, Provincia de Río Negro, vol. 52. Revista de la Asociación Geológica Argentina, pp. 65–80.

Giacosa, R., 2001. Zonas de cizalla Neopaleozoicas en el sector oriental del Macizo Nordpatagonico. Revista de la Asociación Geológica Argentina 56, 131–140.

Giacosa, R.E., Paredes, J.M., 2001. Estructura de las metamorfitas del Paleozoico temprano en el Arroyo. Salado. Macizo Nordpatagónico, Río Negro. Revista de la Asociación Geológica Argentina 56, 141–149.

Gibbs, R.A., Thomas, M.D., 1976. Gravity signature of fóssil plate boundaries in the Canadian Shield. Nature 262, 199–200.

Gibb, R.A., Thomas, M.D., Lapointe, D.L., Mukhopadhyay, M., 1983. Geophysics of proposed Proterozoic sutures in Canada. Precambrian Research 19, 349–384.

González, P.D., Poiré, D., Varela, R., 2002. Hallazgo de trazas fósiles en la Formación El Jagüelito y su relación con la edad de las metasedimentitas, Macizo Nordpatagónico Oriental, Provincia de Río Negro. Revista de la Asociación Geológica Argentina 57, 35–44.

Grecco, L.E., Gregori, D.A., Rapela, C.W., Pankhurst, R.J., Labudía, C.H., 1994. Peraluminous granites in the northeastern section of the North Patagonian Massif, 7 Congreso Geológico Chileno, pp. 1354–1359.

Gregori, D.A., Grecco, L.E., Llambías, E.J., 2003. El intrusivo López Lecube: Evidencias de magmatismo alcalino Gondwánico en el sector sudoeste de la provincia de Buenos Aires, Argentina. Revista de la Asociación Geológica Argentina 58, 167–175.

Gregori, D.A., Bjerg, E.A., Saini-Eidukat, B., 2000. New insights on the Jurassic Granites from Somoncura Region, Patagonia, Argentina. XVII. Simposio sobre la Geología de Latinoamérica. Profil, Stuttgart, Germany, p. 18, 47.

Groeber, P., 1929. Líneas fundamentales de la geología del Neuquén, Sur de Mendoza y regiones adyacentes. Dirección General de Minas, Geología e Hidrogeología, vol. 58. Buenos Aires Publicación, p. 109.

Heiland, C.A., 1951. Geophysical Exploration. Prentice-Hall, New York, p. 1013.

Herrero Ducloux, A., 1946. Contribución al conocimiento geológico del Neuquén extraandino. Boletín de Informaciones Petroleras 23, 245–281.

Hyam, D.M., 1998. Structural Evidence for the Fit of the Falkland Islands in pre-break-up Gondwana Geoscientist, vol. 8, pp. 4–7.

Jacobs, J., Thomas, R.J., Weber, K., 1993. Accretion and indentation tectonics at the southern edge of the Kaapvaal craton during the Kibaran (Grenville) orogeny. Geology 21, 203–206.

Johnston, S.T., 2000. The Cape Fold Belt and Syntaxis, and the rotated Falkland Islands: Dextral transpressional tectonics along the southwest margin of Gondwana. Journal of African Earth Sciences. 31, 51–63.

Kaasschieter, J.P.H., 1965. Geología de la Cuenca del Colorado. 2 Jornadas Geológicas Argentina. Actas 3, 251–271.

Keidel, J., 1916. La geología de las sierras de la provincia de Buenos Aires y sus relaciones con las montañas de Sud Africa y los Andes. Dirección General de Minas, Geología e Hidrología, Buenos Aires, Anales, vol. 9, p. 78.

Keidel, J., 1925. Sobre la estructura tectónica de las capas petrolíferas en el oriente del territorio del Neuquén. Dirección General de Minas, Geología e Hidrología, sección Geología, Buenos Aires, Publicación, vol. 8, p. 67.

Kostadinoff, J., 1992. Configuración y litología del basamento geofísico en el litoral comprendido entre Viedma y San Antonio Oeste, provincia de Río Negro. Revista de la Asociación Geológica Argentina 47, 317–321.

Kostadinoff, J., Labudía, C.H., 1991. Algunas características del basamento en la desembocadura del Río Negro a partir de datos gravimagnetométricos. Revista de la Asociación Geológica Argentina 46, 173–180.

Kostadinoff, J., Llambías, E.J., Raniolo, L.A., Alvarez, G., 2001. Geología y geofísica del sector oriental de la provincia de La Pampa. Revista de la Asociación Geológica Argentina 56, 481–493.

Kostadinoff, J., Llambías, E.J., 2002. Cuencas sedimentarias en el subsuelo de la provincia de La Pampa. 5 Congreso de Exploración y Desarrollo de Hidrocarburos. Mar del Plata, p. 9.

Kostadinoff, J., Gregori, D.A., Raniolo, L.A., 2005. Configuración geofísica–geológica del sector Norte de la provincia de Río Negro. Revista de la Asociación Geológica Argentina 60, 368–376.

Krapez, B., 1999. Stratigraphic record of an Atlantic-type global tectonic cycle in the Paleoproterozoic Ashburton province of Western Australia. Australian Journal of Earth Sciences 46, 71–87.

Kunar, N., Singh, A.P., Gupta, S.B., Mishra, D.C., 2004. Gravity signature, crustal architecture and collision tectonics of the East Ghats mobile belt. Journal of India Geophysical Union 8, 97–106.

Linares, E., Llambías, E.J., Latorre, C.O., 1980. Geología de la Provincia de La Pampa, República Argentina y geocronología de sus rocas metamórficas y eruptivas. Revista de la Asociación Geológica Argentina 35, 87–146.

Llambías, E.J., Leveratto, M.A., 1975. El plateau riolítico de la provincia de La Pampa, República Argentina. 2 Congreso Iberoamericano de Geología Económica, vol. 1. Actas, Buenos Aires, pp. 99–114.

Llambías, E.J., Rapela, C.W., 1984. Geología de los Complejos Eruptivos de la Esperanza, Provincia de Río Negro. Revista de la Asociación Geológica Argentina 39, 220–243.

Llambías, E.J., Melchor, R.N., Tickyj, H., Sato, A.M., 1996. Geología del Bloque del Chadileuvú. 13 Congreso Geológico Argentino y 3 Congreso de Exploración de Hidrocarburos, vol. 5. Actas, Buenos Aires, pp. 417–425.

Llambías, E.J., Varela, R., Basei, M., Sato, A.M., 2002. Deformación y metamorfismo neopaleozoico en Yaminué, Macizo Nordpatagónico (40° 50°S, 67° 40°W): su relación con la fase orogénica San Rafael y el arco de los Gondwánides. 15 Congreso Geológico Argentino. El Calafate, CD-ROM, Article 153, p. 6.

Martinez, C., 1980. Geologie des Andes boliviennes. Travaux et documents de l'Ostrom. París, p. 119.

McMechan, M.E., Thompson, R.E., 1989. Structural style and history of the Rocky Mountain fold and thrust belt. In: Ricketts, B.D. (Ed.), Western Canada Sedimentary Basin: A Case History. Canadian Society of Petroleum Geology and The Open University, pp. 47–72.

Melchor, R.M., 1999. Redefinición estratigráfica de la Formación Carapacha (Pérmico), provincia de La Pampa. Revista de la Asociación Geológica Argentina 54, 99–108.

Nettleton, L.L., 1976. Gravity and magnetics in oil prospecting. McGraw Hill Co, New York. USA, p. 464.

Newton, A.A., Cingolani, C.A., 1990. Aspectos estratigráficos y estructurales comparativas entre las secuencias siluro-devónicas de la Sierra de la Ventana (Argentina) y el Cinturón Plegado del Cabo (Sudáfrica). Revista Técnica de YPFB 11, 59–63.

Orchuela, I.A., Ploszkiewicz, J.V., 1984. La Cuenca Neuquina. In: Ramos, V.A. (Ed.), Relatorio de la Geología y recursos naturales de la Provincia de Río NegroCongreso Geológico Argentino, vol. 9, pp. 163–188.

Pankhurst, R.J., Rapela, C.W., Fanning, C.M., 2001. The Mina Gonzalito gneiss: Early Ordovician metamorphism in northern Patagonia. 3 South American Symposium on Isotope Geology, Pucón, Chile. CD-ROM. SENARGEOMIN, Santiago, pp. 604–607.

Pankhurst, R.J., Rapela, C.W., Fanning, C.M., Márquez, M., 2006. Gondwanide continental collision and the origin of Patagonia. Earth Science Review, 76, 235–257.

Ramos, V.A., 1984. Patagonia: Un continente paleozoico a la deriva? 9 Congreso Geológico Argentino, Actas 2, 311–325.

Ramos, V., Cortes, J.M., 1984. Estructura e interpretación tectónica. In: Ramos, V. (Ed.), Relatorio de la geología y recursos naturales de la provincia de Río Negro. 9 Congreso Geológico Argentino I, pp. 317–346.

Ransome, I.G.D., de Wit, M.J., 1992. Preliminary investigations into a microplate model for the South Western Cape. In: de Wit, M.J., Ransome, I.G.D. (Eds.), Inversion Tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa. Balkema Publishers, Rotterdam, pp. 257–266.

Rapalini, A.E., 1998. Syntectonic magnetization of the mid-Palaeozoic Sierra Grande Formation: further constraints of the tectonic evolution of Patagonia. Journal of the Geológical Society of London, 155, 105–114.

Rapalini, A.E., Vizán, H., 1993. Evidence of intrapangaea movements in West Gondwana. Comptes Rendus XII International Congress of Carboniferous-Permian I, pp. 405–434.

Rapela, C.W., Caminos, R., 1987. Geochemical characteristics of the Upper Paleozoic magmatism in the Eastern sector of the North Patagonian Massif. Revista Brasileira Geociências. 17, 535–543.

Rapela, C.W., Pankhurts, R.J., 2002. Eventos tecto-magmáticos del Paleozoico Inferior en el margen Proto-Atlántico del sur de Sudamérica. 15 Congreso Geológico Argentino. Actas, pp. 24–29.

Ratschbacher, L., Frisch, W., Linzer, H.-G., Merle, O., 1991. Lateral extrusion in the Eastern Alps, Part II: Structural analysis. Tectonics 10, 256–272.

Rossello, E.A., Massabie, A.C., Lopez-Gamundi, O.C., Cobbold, P.R., Gapais, D., 1997. Late Paleozoic transpression in Buenos Aires and northeast Patagonia ranges, Argentina. Journal of South American Earth Sciences 10, 389–402.

Saini-Eidukat, B., Gregori, D., Bjerg, E., Migueles, N., Beard, B., Johnson, C., Vervoort, J. and Gehrels, G.E., submitted for publication. Rb–Sr and U–Pb age systematics of the Alessandrini Silicic Complex and related rocks, El Cuy region, northern Patagonia, Argentina. Journal of South American Earth Sciences.

Sato, A.M., Tickyj, H., Llambías, E.J., 1996. Geología de los granitoides aflorantes en el sur de la provincia de La Pampa, Argentina. 13 Congreso Geológico Argentino and 3 Congreso de Exploración de Hidrocarburos, vol. 5, pp. 429–439.

Sato, A.M., Tickyj, H., Llambías, E.J., Sato, K., 2000. The Las Matras tonalitic–trondhjemitic pluton, Central Argentina: Grenvillian age constraints, geochemical characteristics, and regional implications. Journal of South America Earth Sciences, 13, 587–610.

Sellés Martínez, J., 1989. The structure of the Sierras Australes (Buenos Aires province, Argentina): an example of folding in a transpressive environment. Journal South American Earth Sciences 2, 317–329.

Söhnge, A.P.G., 1983. The Cape Fold Belt — perspective. In: Söhnge, A.P.G., Hälbich, I.W. (Eds.), Geodynamics of the Cape Fold Belt, vol. 12. Geological Society of South Africa, Special Publication, pp. 1–6.

Tapponnier, P., Molnar, P., 1976. Slip-line theory and large-scale continental tectonics. Nature 264, 319–324.

Telford, W., Geldart, L., Sheriff, R., 1990. Applied Geophysics, Chapter 6. Cambridge University Press, Cambridge, pp. 293–297.

Tickyj, H., Dimieri, L., Llambías, E.J., Sato, A.M., 1997. Cerro de Los Viejos (38° 28°S–64° 26°O): cizallamiento dúctil en el sudeste de La Pampa. Revista de la Asociación Geológica Argentina 52, 311–321.

Tickyj, H., Llambías, E.J., Sato, A.M., 1999. El basamento cristalino de la región sur-oriental de la provincia de La Pampa: Extensión austral del Orógeno Famatiniano de Sierras Pampeanas. 14 Congreso Geológico Argentino, vol. 1. Actas, pp. 160–163.

Tickyj, H., Llambías, E.J., Melchor, R.N., 2002. Ordovician rocks from La Pampa Province, Argentina. In: Aceñolaza, F.G. (Ed.), Aspects of the Ordovician System in Argentina. (Serie Correlación Geológica, vol. 16. Instituto Superior de Correlación Geológica, Tucumán, pp. 257–266.

Tomezzoli, R.N., Vilas, J.F., 1996. Paleomagnetismo del Grupo Pillahuincó en Sierra de la Ventana (estancias Las Julianas y San Carlos). 13 Congreso Geológico Argentino and 3 Congreso de Exploración de Hidrocarburos, vol. 2. Actas, pp. 481–488.

Thomas, M.D., 1983. Tectonic significance of paired gravity anomalies in southern and Central Appalachians. In: HatcherJr. Jr., R.D., Williams, H., Zietz, I. (Eds.), Contributions to Tectonics and Geophysics of Mountain Chains, vol. 158. Geological Society of America, Memoir, Boulder, pp. 113–124.

Turner, J.C.M., Baldis, B.A.J., 1978. La estructura transcontinental del límite septentrional de la Patagonia. 7 Congreso Geológico Argentino, vol. 2. Actas, pp. 225–238.

Varela, R., Basei, M.A.S., Sato, A.M., Sita Jr., O., Cingolani, C.A., Sato, K., 1998. Edades isotópicas Rb/Sr y U/Pb en rocas de Mina Gonzalito y Arroyo Salado. Macizo Nordpatagónico Atlántico, Río Negro, Argentina, 10 Congreso Latinoamericano de Geología and 5 Congreso Nacional de Geología Económica, vol. 1, pp. 71–76.

Vaughan, A.P.M., Pankhurst, R.J., 2008. Tectonic overview of the West Gondwana margin. In: Casquet, C., Pankhust, R.J., Vaughan, A.P.M. (Eds.), The West Gondwana margin: Proterozoic to MesozoicGondwana Research, vol. 13, pp. 150–162.

Vergani, G.D., Tankard, A.J., Belotti, H.J., Welsink, H.J., 1995. Tectonic evolution and paleogeography of the Neuquén basin, Argentina. In: Tankard, A.J., Suárez, S., Welsink, H.J. (Eds.), Petroleum basins of South AmericaAmerican Association of Petroleum Geologists, Memoir, vol. 62, pp. 383–402.

von Gosen, W., Buggisch, W., Dimieri, L.V., 1990. Structural and metamorphic evolution of the Sierras Australes (Buenos Aires Province/Argentina). Geologische Rundschau 79, 797–821.

von Gosen, W., 2002. Polyphase structural evolution in the northeastern segment of the North Patagonian Massif (southern Argentina). Journal South American Earth Sciences 15, 591–623.

von Gosen, W., 2003. Thrust tectonics in the North Patagonian Massif (Argentina). Implications for a Patagonia Plate. Tectonics 22, 5/1–5/33.

Wellman, P., 1978. Gravity evidence for abrupt changes in mean crustal density at the junction of Australian crustal blocks. Journal of Australian Geology and Geophysics 3, 153–162.

Williams, H.A., Cassidy, J., Locke, C.A., Spörli, K.B., 2006. Delineation of a large ultramafic massif embedded within a major SW Pacific suture using gravity methods. Tectonophysics 424, 119–133.

Windhausen, A., 1914. Contribución al conocimiento geológico de los territorios de Río Negro y Neuquén, con un estudio de la región petrolífera de la parte central de Neuquén (Cerro Lotena y Covunco). Anales del Ministerio de Agricultura, sección Geología, Mineralogía y Minería, X, p. 60.

Windhausen, A., 1931. Geología Argentina. II Parte. Geología Histórica y regional del territorio argentino, Peuser, Buenos Aires, p. 645.