Journal of Geodynamics 50 (2010) 243–255

Contents lists available at ScienceDirect

Journal of Geodynamics

journal homepage: http://www.elsevier.com/locate/jog

Pampia: A large cratonic block missing in the Rodinia supercontinent

Victor A. Ramos[a,d,*], Graciela Vujovich[a,d], Roberto Martino[b,d], Juan Otamendi[c,d]

[a] Laboratorio de Tectónica Andina, FCEyN, Universidad de Buenos Aires, Buenos Aires, Argentina
[b] Cátedra de Geología Tectónica, Universidad Nacional de Córdoba, Córdoba, Argentina
[c] Departamento de Geología, Universidad Nacional de Río Cuarto, Río Cuarto, Argentina
[d] CONICET(Consejo Nacional de Investigaciones Científicas y Técnicas), Argentina

ARTICLE INFO

Article history:
Received 21 October 2009
Received in revised form 16 January 2010
Accepted 30 January 2010

Keywords:
Andes
Amazonia
Paranapanema
Mesoproterozoic
Grenville
Clymene

ABSTRACT

The large cratonic block of Pampia, at present in southern South America, is commonly missing in recent comprehensive reconstructions of Rodinia. This block was the conjugate margin of the Amazonia craton that corresponds to the W-NW-trending segment of the Sunsás orogen. This segment developed between Sucre in Bolivia and Corumbá in Brazil as a result of a Mesoproterozoic collision. The western margin of Pampia partially coincides with the southern part of the Arequipa-Antofalla terrane that was also amalgamated during the Mesoproterozoic. The Cuyania terrane, a Laurentian rifted continental block, was accreted to the southern sector of this margin of Pampia in middle Ordovician times. The northern sector of the eastern margin of Pampia is the lower plate of the Brasiliano belt developed along the Paranapanema craton during the early Cambrian collision associated with the closure of the Clymene Ocean. The southern sector of the eastern margin partially coincides with the southern extension of the Transbrasiliano lineament, which juxtaposed the Rio de La Plata Craton with the Pampia cratonic block. Along this eastern margin the Pampean-Paraguay orogen was formed during the late Brasiliano cycle in latest Proterozoic-Early Cambrian time. The southern margin was generated by the collision of Patagonia during late Paleozoic times. This cratonic block of Pampia, so defined, has western and northern sectors formed by Mesoproterozoic orogens, while the eastern sector is partially formed by juvenile Neoproterozoic crust, although older rocks cannot be ruled out. The Pampia cratonic block was the locus of several magmatic belts associated with important metamorphism during the Paleozoic and preserved in the central part at lower crustal levels.

1. Introduction

Early paleogeographic reconstructions of the South American basement show a series of metamorphic rocks of Precambrian-Early Paleozoic age surrounding the southwest margin the South American Platform (Fig. 1) (de Almeida, 1970; see de Almeida et al., 2000 for a recent review). These peripheral exposures of metamorphic rocks correspond to the outcrops of the Sierras Pampeanas, a series of basement blocks uplifted during the Andean orogeny (González Bonorino, 1950; Caminos, 1979; Casquet et al., 2008). These basement outcrops are bounding the Rio de la Plata Craton to the west, and they are characterized by discontinuous exposures over 1600 kilometers from latitude 26°S to 39°S.

Since the early proposals that considered this metamorphic basement as the result of the collision between Rio de La Plata and a Pampean block at the end of the Proterozoic (see Ramos, 1988, and references therein), a large advance in geological knowledge has permitted the definition of a complex history of deformation, metamorphism and magmatism. The objective of this review is to update the large amount of information available about the basement of the Sierras Pampeanas and adjacent terranes in a coherent tectonic framework in order to propose a more precise reconstruction of Rodinia in the analyzed sector following recent proposals of Li et al. (2008), Santosh et al. (2009) and others, where this cratonic basement is faintly recognized.

These basement outcrops have been integrated in a large cratonic block defined as Pampia (Fig. 1) that occupied the central and northern region of Argentina (Ramos and Vujovich, 1993), which Brito Neves et al. (1999) and de Almeida et al. (2000) among others, located bounded by the Amazonian and Rio de La Plata cratons and the Paranapanema (or Parana) cratonic block (Mantovani and Brito Neves, 2005; Fuck et al., 2008; Cordani et al., 2009).

The basement of Sierras Pampeanas encompasses two magmatic belts with arc affinities. The eastern belt comprises a

* Corresponding author at: Laboratorio de Tectónica Andina, FCEyN, Universidad de Buenos Aires, Buenos Aires, Argentina. Tel.: +54 11 4701 6947.
E-mail address: andes@gl.fcen.uba.ar (V.A. Ramos).

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doi:10.1016/j.jog.2010.01.019

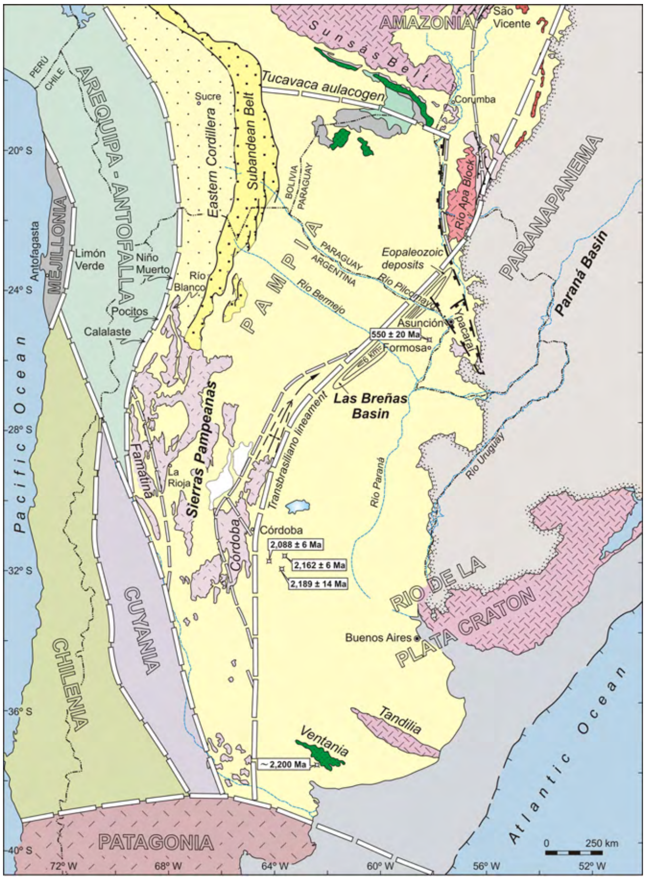

Fig. 1. The Pampia cratonic block and its relationships with adjacent cratons and Paleozoic terranes in southern South America. Isopachs of Las Breñas Basin after Wiens (1995).

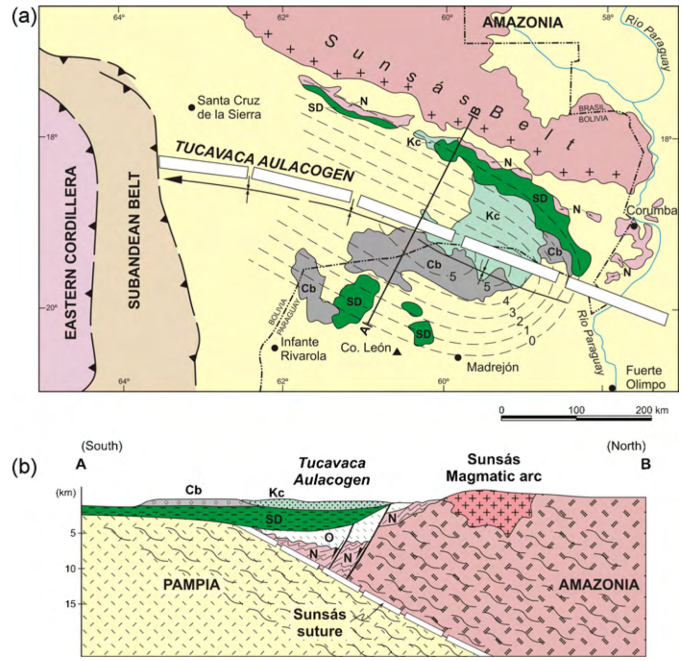

Fig. 2. (a) Geological map of Tucavaca aulacogen with indication of the subsurface boundary between Amazonia and Pampia. Schematic isopach contours are after Clebsch Kuhn (1991); (b) structural section of the northern boundary of the Pampia cratonic block showing the deformation of the Sunsás belt and the extensional structures that controlled the sedimentation in Neoproterozoic, Cambrian and Ordovician times (based on Clebsch Kuhn, 1991 and Trompette, 1994).

late Proterozoic–Early Cambrian magmatic and metamorphic belt bounded by ophiolitic rocks known as the Pampean orogen. The western belt comprises a similar belt of Ordovician age named as the Famatinian orogen.

The first comprehensive evolution of the basement of the eastern Sierras Pampeanas was presented by Kraemer et al. (1995) who explained the geological history of this region as the result of the collision of the Pampia terrane against the Rio de La Plata craton during the latest Proterozoic. This study emphasized the important orthogonal deformation observed in the kinematic indicators of the large megashears that crossed the basement with an approximated N-NW trend (Martino et al., 1993). New geochronological data presented by Rapela et al. (1998) extended the collision up to the Early Cambrian.

Subsequent work along the western margin of the western Sierras Pampeanas defined a magmatic arc of mainly Ordovician age interpreted as the upper plate of a subduction zone developed between the basement of Precordillera and the Pampean block (Ramos et al., 1986; Rapela et al., 1992; Pankhurst et al., 1998). Although most of the research performed in those days was concentrated on the relationships between the different magmatic arcs, their geochemical and isotopic composition, and the differences in ages between the eastern and western Sierras Pampeanas, only little attention was paid to the extent, boundaries and precise composition of the Pampia cratonic block. Therefore, we are going first to define as precisely as possible the extent and outline of the Pampia cratonic block, and later on to describe the intrinsic characteristics of the basement.

2. Northern boundary

The northern boundary goes from the city of Sucre in central Bolivia to Corumbá in south-western Brazil, as originally proposed by Ramos and Vujovich (1993) (Fig. 2). This coincides with an extensional regional structure with a N75°W trend known as the Tucavaca aulacogen (Avila-Salinas, 1992) or Chiquitos graben (Trompette, 1994) in Bolivia, or the Curupaity basin in Paraguay (Clebsch Kuhn, 1991; Wiens, 1995). These units are aligned with the eastern end of the basin, recognized also as the Tucavaca aulacogen by Dantas et al. (2009) (see Fig. 2), which is orthogonal to the Corumbá graben defined east of this city by Trompette et al. (1998).

The exposed basement along this belt comprises the metamorphic and igneous rocks of the Sunsás belt, exposed immediately north of the Tucavaca aulacogen, which was described by Sadowski and Bettencourt (1996). Recent precise dating indicated a time span of 1280–950 Ma for the main deformation and subduction related magmatism followed by important intra-crustal S-type magmatism that occurred at about 1000 Ma (Cordani et al., 2009). The Sunsás orogenic belt was the result of a Middle Proterozoic collision between Pampia and Amazonia cratonic blocks at these latitudes. Further north, out of the area covered in Fig. 1, the Paragua terrane is placed between Laurentia and Amazonia, as a result of a Mesoproterozoic collision prior to the final closure of the Sunsás belt (Boger et al., 2005). The eastern region under study after the Grenvillian deformation remain amalgamated and only record minor intraplate deformation during the Late Proterozoic and Phanerozoic times as proposed by Trompette (1994).

The area was the focus of important extension during the Late Proterozoic as recorded in the sedimentary sequences of the Boqui and Tucavaca Groups (Suárez Soruco, 2000). These sequences are represented by turbiditic successions of Neoproterozoic to Early Cambrian age up to more than 2000 m thick. They have typical Vendian ichnofossils in the upper unit reported by Durand (1993) and correlated with the Puncoviscana Formation in northwestern Argentina (Omarini et al., 1999; Aceñolaza and Aceñolaza, 2005).

In the foothills of Sierras Chiquitanas a foreland thrust-belt is exposed with an W-SW vergence that developed during the Pampean deformation. This indicates some shortening in the Early Cambrian between the Amazonia and Pampia cratons in the westernmost region as described by O'Connors and Walde (1987). The metamorphism associated with this deformation produced low greenschist facies (Montemurro-Diaz, 1991) and is devoid of any magmatism with the exception of two minor granitic stocks of San José and Santiago in the south-western margin of Tucavaca aulacogen (França et al., 1995). A sequence of Early Paleozoic marine sediments of Ordovician to Devonian age is unconformably overlying the Tucavaca Group (Suárez Suroco and Díaz Martínez, 1996).

These sedimentary successions are also known in Paraguay in the eastern extension of the Chiquitos graben, where they constitute the Curupaity basin with a sedimentary fill exceeding 5200 m (Wiens, 1995). These deposits comprise marine platform sandstones and shales of Ordovician to Devonian age, with their depocenter aligned with the Tucavaca aulacogen. Marine Carboniferous sandstones and continental red beds of Permian and Early Triassic age are unconformably deposited on the early Paleozoic sediments. All the Paleozoic units are poorly deformed and affected at the base by normal faults. Deposits equivalent to the Tucavaca Group are not exposed in northern Paraguay, but they are exposed east of Asunción, where they are known as the Itapucumi carbonates and clastics, along the western margin of the Paraguay River (Clebsch Kuhn, 1991). These rocks have been correlated to the Puncoviscana Formation by Durand (1993) based on the ichnofauna, but in the eastern side present a more carbonatic composition in the upper part of the section.

East of the Corumbá two units are distinguished: the metasediments of Brasiliano age that are correlated with the Cuiabá Group and a cratonic cover with cap carbonates and glacial deposits (de Alvarenga et al., 2008; Dantas et al., 2009).

Based on the brief description of the Tucavaca aulacogen, a geological surface map and a structural cross-section are presented in Fig. 2, which depicts the interaction between the Pampia and Amazonia cratonic blocks during the Neoproterozoic and Paleozoic. The Amazonian craton was the upper plate in the Mesoproterozoic when the Sunsás magmatic arc was developed by consumption of the oceanic crust attached to the Pampia cratonic block. The collision, followed by important granitization, occurred at about 1000 Ma. The Mesoproterozoic metamorphic rocks are exposed mainly on the Bolivian and Brazilian side while in the southern block a wide deformation belt related to the Sunsás orogen is inferred. The presence of a Grenvillian basement is based on indirect evidence as shown by the important frequency peak between 1000 and 1100 Ma identified in the detrital zircons of the cover. For example, U-Pb ages in detrital zircons in the Puncoviscana Formation of the Eastern Cordillera have the most important frequency peak between 1200 and 1000 Ma (Adams et al., 2008; Hauser et al., 2009); further south in the equivalent metamorphic rocks of the Ancasti area have a frequency peak of 1034 ± 20 Ma (Adams et al., 2009); and at the base of the clastic cover corresponding to the Cambrian quartzites of the Mesón Group between 1000 and 900 Ma (Adams et al., 2008, 2009). The sediments of this cover were derived from the Sunsás orogen, in close proximity during different stages of exhumation. Zircons in Puncoviscana Formation, probably derived from the Rio Apa block, display minor frequency peaks around 1700–1800 Ma (Adams et al., 2008) that are correlated to similar ages as reported by Cordani et al. (2009) from this block.

Soon after that collision the first evidence of rifting is recorded in the upper plate with the emplacement of mafic sills in southern Brazil of ca. 985 Ma (Elming et al., 2009) and the Rincón del Tigre mafic and ultramafic rocks of ca. 990 Ma in Bolivia (Cordani et al., 2009). This extension led to the formation of the Tucavaca aulacogen, which was orthogonal to the Puncoviscana belt in the western side (Ramos, 2008) and to the Paraguay belt in the eastern side (de Alvarenga et al., 2000). The Pampean orogeny on the western side produced the Chiquitanas foreland fold and thrust belt in the Tucavaca Group, and the Brasiliano late deformation in the Corumbá region. The structures of the Late Proterozoic–Early Cambrian are not known in the central region of the aulacogen because the basement has never been reached by drilling in Paraguay (Clebsch Kuhn, 1991).

The subsequent evolution alternated taphrogenic sedimentation and thermal subsidence during the whole Paleozoic, the Early Triassic, and up to the Cretaceous. Unconformities at the base of the Ordovician, Carboniferous and the Late Permian marked pulses of subsidence and sedimentation in an extensional environment.

3. Northeastern boundary

This sector comprises the boundary between Pampia and the basement of the Paraná Basin (Alto Paraguay cratonic block of Ramos, 1988; Paraná Block of Cordani et al., 2003; Tohver et al., 2006; Paranapanema craton of Mantovani et al., 2005; Fuck et al., 2008). The Paranapanema cratonic block, as it is designed in this work, is also omitted in many of the Rodinia reconstructions despite it is larger than 400,000 km^2 (Mantovani and Brito Neves, 2005).

Most of the northeastern sector of Pampia is covered by a thick sequence of Cenozoic sediments. The neighboring basement is only known by drilling in the western part of Argentina (Ramos, 1988), some minor outcrops in eastern Paraguay (Harrington, 1950), and further north in the Sierra de Bodoquena in Brazil (Dantas et al., 2009). The geophysical studies of Mantovani et al. (2005) recognized the presence of the Paranapanema craton as a stable undeformed area with a nucleus as depicted in Fig. 3. This quiet central part is bounded by an area of high gravity gradients that coincides with collisional structures produced during the late Brasiliano orogeny. The Paranapanema craton was the upper plate

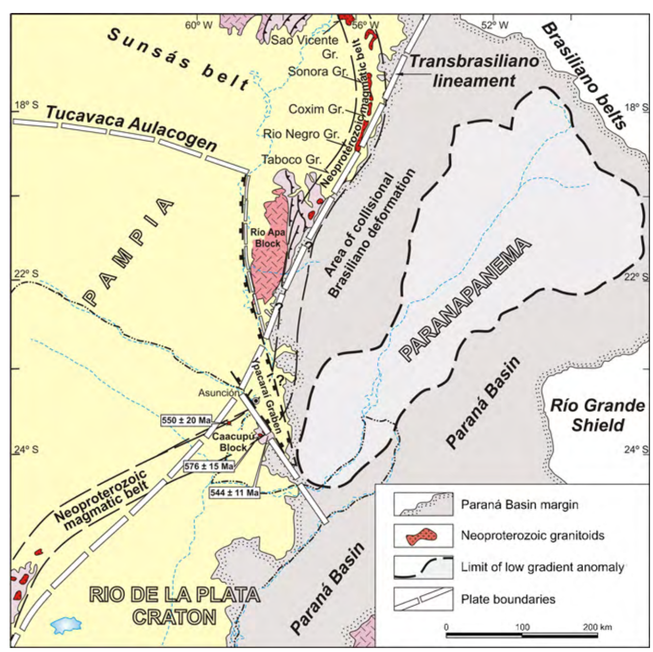

Fig. 3. Geological map of the northeastern boundary of the Pampia craton with indication of the main structural features discussed in the text (based on Ramos and Vujovich, 1993; Brito Neves et al., 1999; Mantovani et al., 2005 and de Alvarenga et al., 2008). The Transbrasiliano lineament has been modified from Feng et al. (2004) after Cordani et al. (2009).

during the Neoproterozoic subduction (Mantovani and Brito Neves, 2005). The polarity of this subduction is inferred from the vergence of the Paraguay foreland fold and thrust belt, which has a tectonic transport to the west and northwest, and the magmatism of that age on the western side (Ramos, 1988; Manzano et al., 2008).

The southeastern Amazonia craton is covered by an undeformed to weakly deformed internal domain, where gently-dipping strata fill a siliciclastic foredeep of the Alto Paraguay Group at the margin of the craton (Nogueira et al., 2007), and an external domain, where folds and thrust faults have developed on the carbonate and siliciclastic rocks of the Ararás and Alto Paraguay groups. The Ararás Group carbonates and underlying glacial deposits have been interpreted as a passive margin by Dantas et al. (2009). These sequences are underlain by phyllites and quartzites folded and metamorphosed up to greenschist facies during the Brasiliano Orogeny in late Neoproterozoic-early Cambrian times. This low-grade metamorphic sequence is represented by the Cuiabá Group. These metamorphic rocks are intruded by postcollisional granites, dated as the São Vicente granite at 504 ± 8.9 Ma; the Varginha granite at 505 ± 4.1 Ma and the Araguacema granite at 509 ± 2.7 Ma (Godoy et al., 2007). A belt of intrusive with similar characteristics extend further south, as the Sonora, Coxim, Rio Negro and Taboco granites, granodiorites and quartzdiorites, reaching the boundary with Paraguay, and interpreted as syn- and post-collisional suites (Godoy et al., 2007; Manzano et al., 2008).

The Neoproterozoic deformation was interpreted as the result of the collision between the Amazonia craton and the Sao Francisco craton in the northern part, and with the Paranapema block in the southern segment (Tohver et al., 2006). This collision was the consequence of the closure of the Clymene Ocean developed along the eastern side of the Amazonia Craton in the Neoproterozoic (Trindade et al., 2006). Recent geochronological and paleomagnetic studies in the Paraguay belt show that deformation overlaps with the timing of the Pampean orogeny further south along the eastern margin of the Pampia cratonic block (Tohver et al., 2010). This suggests a coeval closure for the Clymene Ocean separating the Amazonian craton from the São Francisco and Rio de la Plata cratons.

The basement of these units in the southern part of Brazil and northern part of eastern Paraguay is formed by the Rio Apa block (Fig. 3). This block is composed of gneisses intruded by monzogranites with Paleoproterozoic ages. There are also several orthogneisses of magmatic arc affinities of 1700–1760 Ma metamorphosed at medium to high level. The area was pervasively heated at 1300 Ma (Cordani et al., 2008). This old basement, in the east, has been reactivated by deformation and metamorphism in the late Brasiliano cycle associated with Neoproterozoic-Early Cambrian granites. The older suites indicate a common history between the Amazonian Craton and the Rio Apa block, which looks like a dismembered piece of the large craton deformed during the late Brasiliano orogeny (Cordani et al., 2009).

Another basement block is exposed in southeastern Paraguay, known as Caapucú high (Fúlfaro, 1996). This southern block, which in this area is intruded by granitic rocks, was traditionally correlated to the Río de la Plata craton. This correlation is confirmed by U-Pb ages in inherited zircons from migmatites that yielded nearly concordant $^{207}Pb/^{206}Pb$ dates of 2023 ± 12 Ma (Cordani et al., 2001). The basement consists of ortho- and paragneisses, amphibolites, talc schists and rhyolite dikes of the Río Tebicuary Complex. This basement is intruded by granites and granodiorites of the Caapucú Group (Kanzler, 1987). K-Ar dating available from these rocks indicates ages between 544 ± 11 Ma and 576 ± 15 Ma (Bistchene and Lippolt, 1985). Recent SHRIMP U-Pb dating on zircons from migmatites and granodiorites gave concordant $^{207}Pb/^{206}Pb$ dates between 624 ± 12 Ma and 622 ± 15 Ma that confirm Brasiliano crystallization ages of this belt (Cordani et al., 2001). The eastern margin of this basement is affected by NNE-trending shear zones (Kanzler, 1987) that, exposed at the surface, near San Miguel town, displays mafic and ultramafic rocks interpreted as a dismembered greenstone belt by Schalamuk et al. (1989).

It is important to remark that between the Rio Apa block and the Caapucú high there is a trough more than 5000 m deep filled by early and late Paleozoic and younger rocks (Fúlfaro, 1996). This trough has been reactivated during Cretaceous extension with the development of the Ypacarai graben associated with alkaline intrusives (Wiens, 1995). Gravimetric and magnetometric data show that this deep trough is bounded by NNW to NW trending normal faults that truncate the Rio Apa block (Riccomini et al., 2001).

The basement of the Caapucú block of southern Paraguay is correlated with the Rio de la Plata craton. The geophysical studies of Mantovani et al. (2005) and Mantovani and Brito Neves (2005) show that this block is slightly separated from the Paranapanema craton (Fig. 3). The nucleus of this cratonic block is truncated to the south by a NW-trending lineament. A similar orientated structural trend truncates the northern margin of the Paranapanema block, as shown by Assumpção et al. (2006) based on the upper mantle anisotropy. The southern lineament may separate the Paranapanema block from the Rio de La Plata craton (see Fig. 3).

At the western margin of the Paranapanema block, the basement is known in the subsurface of the Chacoparaná Basin. Oil drilling near Formosa (Fig. 3) reached granitic rocks dated by K-Ar in 550 ± 20 Ma (Ramos, 1988), with similar ages and characteristics as in southern Paraguay.

Based on the present knowledge of the region and following the early hypothesis of Kraemer et al. (1995) and the most recent of Trindade et al. (2006) is proposed that the Tucavaca aulacogen in the eastern end was truncated and deformed by the late Brasiliano orogeny, recognized as the Pampean-Paraguay orogen by Brito Neves et al. (1999) and Tohver et al. (2010). The deformation is linked to the closure of the Clymene Ocean and subsequent collision of the Paranapanema cratonic block with the Amazonia and Pampia cratons. These last two cratonic blocks were amalgamated during Mesoproterozoic times and subsequently reactivated by extension in the Neoproterozoic, Ordovician and late Paleozoic times.

Most of the authors that studied the Rio Apa block concluded that this basement is part of the Amazon craton based on the common history of both areas. The studies of Feng et al. (2004) have shown, based on 3D lithospheric tomography, that an important discontinuity, known as the Transbrasiliano lineament, separates the Amazonia craton from the São Francisco craton. This important feature is identified southward until the Pantanal area. Recently, it has been proposed by Rapela et al. (2008) that this lineament is bounding the eastern Sierras Pampeanas. If this hypothesis is accepted the Transbrasiliano lineament bounds the eastern side of the Rio Apa block as proposed by Cordani et al. (2009), joining the lineament identified by Feng et al. (2004). Although the precise trace of the Transbrasiliano lineament is still an open question, it is important to note that the Las Breñas Basin in Argentina and its extension in Paraguay, more than 6000 m thick, is west-bounded by a conspicuous fault (Wiens, 1995), here related to the Transbrasiliano lineament (Fig. 1).

4. Eastern boundary

The boundary between Pampia and the Rio de La Plata craton is not exposed (Fig. 1). However, a strong gravimetric anomaly identified in the central part of the foothills of the Sierras de Córdoba by Miranda and Introcaso (1996) indicates a first order crustal discontinuity that has been related to the collision with the Rio de la Plata Craton and a Neoproterozoic suture (Ramos, 1988; Escayola et al., 2007).

The eastern Sierras Pampeanas, indicated as Córdoba in Fig. 1, has a series of discontinuous and dismembered ultramafic belts that are tectonically intercalated with metamorphic rocks with Barrovian-type facies, which constitute the Pampean orogen. Along the eastern side of the Valle de Chancaní an Andean fault, the Pocho Fault, uplifted the whole western flank of the Sierras de Córdoba (see location in Fig. 6). This fault seems to reactivate the early Paleozoic ductile shear zone of Guacha Corral (Martino, 2003).

The crustal discontinuity of the eastern margin of Sierras de Córdoba has been correlated with the Transbrasiliano lineament, a continental scale lineament that bounds further north Amazonia from the Sao Francisco craton (Kröner and Cordani, 2003) and Amazonia from the Paranapanema craton (Feng et al., 2004). At the Córdoba latitudes this lineament separates Pampia form the Rio de La Plata Craton (López de Luchi et al., 2005; Rapela et al., 2007; Favetto et al., 2008).

5. Western boundary

The western boundary has two distinct segments: a northern sector (18°–26°SL), where it is based on indirect evidence because the extensive Cenozoic volcanic and sedimentary cover with isolated patches of basement preserved in upper crustal levels (Coira et al., 1999), and a southern sector (26°–32°SL) where the lower crustal levels are exposed and there is striking evidence of a discontinuity (Introcaso et al., 2004; Otamendi et al., 2009).

5.1. Northern sector

The Cambrian and Ordovician sedimentary cover unconformably overlies folded and thrust low-grade schists and metasediments of the Puncoviscana Formation (Omarini et al., 1999; Mángano and Buatois, 2004; Aceñolaza and Aceñolaza, 2005). The Eopaleozoic lithofacies indicate westward deepening of the basin, where turbidites and deeper facies are preserved west of a hinge line that separates the platform deposits from slope deposits. This hinge line has been interpreted as a break in the basement associated to an attenuated crust that toward the west interfingered with basic and ultrabasic rocks identified as ophiolites in Calalaste, Pocitos (see location in Fig. 1), and further north (Allmendinger et al., 1983; Ramos, 1988). Other authors interpreted this shelf break as an attenuated crust associated with intraplate magmatism (Astini, 2003, 2008). Some other alternatives assumed that the ultrabasic rocks of Calalaste are Precambrian in age and the basic and related acidic rocks have an arc-back-arc signature (Zimmermann et al., 1999; Kleine et al., 2004). However, the gabbros and serpentinites of Sierra de Calalaste are associated with dacites and rhyolites of an island arc setting with Late Cambrian U-Pb zircon ages (495 ± 3 Ma). Their ε Nd values are +5.78 to +7.09 (Pinheiro et al., 2008). Pb isotopic compositions are nonradiogenic. Escayola et al. (2009) interpreted these rocks as pieces of a proto-oceanic setting developed along the western margin of Gondwana during the Middle to Late Cambrian. Similar ages have been obtained further north near Tastil (see Fig. 1) in metadacites in El Niño Muerto (495 ± 4 Ma) and in the basalts of Río Blanco (501 ± 9 Ma) with εNd(t) of +2.47 to +4.46, and TDM model ages between 0.84 and 1.12 Ga (Hauser et al., 2008).

This belt coincides with the limit between the Arequipa-Antofalla terranes and the Amazonia and Pampia cratons, suture developed in Mesoproterozoic times during the final amalgamation of Rodinia (Ramos, 2008 and cites therein). Recent studies of Mamaní et al. (2008) precisely outline this boundary based on isotopic and geophysical data. This boundary has a history of reactivations through time as depicted in the Cordillera Real of Bolivia by Jiménez et al. (2009), who illustrates extensional reactivation from late Paleozoic to the Oligocene-Early Miocene along the suture. This suture is also controlling crustal and lithospheric mantle delamination as shown by Beck and Zandt (2002).

5.2. Southern sector

This sector comprises a segment where the Sierras Pampeanas are well exposed (Fig. 1). Geophysical data including gravity (Introcaso et al., 2004) and reprocessed deep seismic reflection data (Snyder et al., 1990; Zapata, 1998), as well as local shear-wave tomographic models (Gilbert et al., 2006), show a sharp boundary between the two adjacent and contrasting crusts of Pampia and the Cuyania terrane. Recent aeromagnetic surveys have recognized a mafic and ultramafic belt interpreted as a suture in the Cuyania composite terrane (Chernicoff et al., 2009a).

This boundary coincides with basement exposures of high to medium grade metamorphic rocks developed in close association with the Famatinian orogen of Early to Middle Ordovician age (Coira et al., 1982; Rapela et al., 1998, 2001; Otamendi et al., 2008, 2009; Chernicoff et al., 2010). This Ordovician high-grade metamorphic episode is superimposed onto a Pampean metamorphism developed in lower metamorphic facies that corresponds to the Pampean deformation (Toselli et al., 1996).

Lower crustal rocks are exposed along this first order crustal discontinuity that is interpreted as the suture between Pampia and the Cuyania terrane at these latitudes (Ramos, 2004).

6. Southern boundary

This sector has a thick cover of Cenozoic sediments. The structural fabric of the basement was interpreted from aeromagnetic and gravimetric surveys validated by the study of a series of isolated minor exposures (Chernicoff et al., 2009b, and references therein). The fabric has a north-south trend almost parallel to the Pampia boundaries.

Geochronological data show along the western margin of Pampia a magmatic arc developed between 475 and 470 Ma (Fig. 4), typical ages of the Famatinian arc. The exposures are described in Paso del Bote where tonalites and diorites were dated at 475.7 ± 2.3 Ma (U-Pb SHRIMP zircon age of crystallization, Villar et al., 2005) emplaced in biotite-garnet schists and gneisses (Tickyj et al., 1999). These rocks have been metamorphosed at 464.7 ± 7.3 Ma (U-Pb SHRIMP in metamorphic zircons, Chernicoff et al., 2009b). The magmatic arc is bounding the western side of the Pampia craton and is truncated to the south by the Huincul High, a testimony of the Late Paleozoic collision of Patagonia against the Gondwana margin (Chernicoff and Zappettini, 2004; Kostadinoff et al., 2006; Mosquera and Ramos, 2006).

The central and eastern parts of this sector are characterized by metasediments and amphibolites exposed in the Sierra de Lonco Vaca and the Green quarry in greenschist facies. The youngest detrital metamorphic zircons from the Green quarry have 500 ± 3 Ma and 515 ± 4.6 Ma from Sierra de Lonco Vaca, and correspond to the Pampean metamorphic episode (Chernicoff et al., 2007, 2009b). According to these authors these rocks belong to a Lower Paleozoic supracrustal sedimentary sequence originated in a foreland basin that was metamorphosed during the Famatinian orogeny.

The Santa Helena schists, a few kilometers to the east of Valle Daza, are metamorphosed in high amphibolite to low granulite facies. These rocks have Mesoproterozoic and Neoproterozoic detrital zircons with a minimum age of 556 ± 4 Ma (U-Pb SHRIMP, Zappettini et al., 2009). These authors interpreted the source of the metasediments as a Grenvillian magmatic arc (1023–1084 Ma), with dominant juvenile zircons as inferred from the Hf isotopic composition (εHf = +0.38 to +10.93), which constitute the basement of the Pampia terrane at these latitudes.

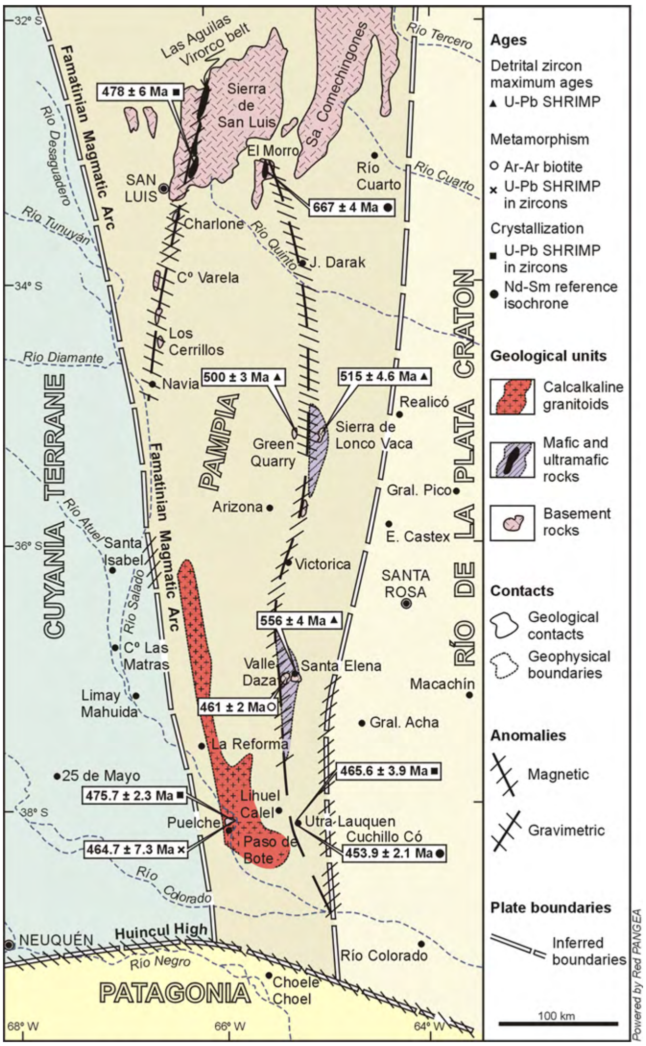

Fig. 4. Southern extension of the Pampia cratonic block (based on Chernicoff and Zappettini, 2004; Kostadinoff et al., 2006 and cites there in; Delpino et al., 2005). Note that most of the area is covered and the boundaries are located by geophysical methods evaluated through small and scattered basement outcrops.

Metamorphic ages from biotite-garnet schists to gneisses of Valle Daza of ca. 461 Ma (Ar/Ar in biotite; Tickyj et al., 1999) are correlated with the Lonco Vaca and Paso del Bote area. This metamorphism is related to the docking of the Cuyania terrane.

A belt of mafic and ultramafic rocks between Charlone and Cerro Varela (Fig. 4) was interpreted from aeromagnetic and gravimetric data as the southern extension of Las Aguilas-Virorco belt of the Sierra de San Luis by Kostadinoff et al. (2006 and cites therein). This belt of gabbros and ultrabasic rocks has been interpreted as a backarc belt dated as 478 ± 6 Ma (zircon age U-Pb SHRIMP; Sims et al., 1998), parallel to the magmatic arc (Kostadinoff et al., 2006).

Another aeromagnetic anomaly has been recognized between the Sierra de Lonco Vaca and Valle Daza exposures and interpreted as a backarc belt (Chernicoff et al., 2009b). This belt was correlated by Delpino et al. (2005) based on gravimetric data with the amphibolites of the El Morro belt described as metamorphosed tholeiitic basalts emplaced either in a backarc setting by Delakowitz et al. (1991) or as an island arc system by Brodtkorb et al. (2006). These rocks have been dated by these authors as 667 ± 4 Ma (Nd-Sm reference isochrone), and correlated with some other mafic belts of Sierras de Córdoba (Escayola et al., 2007).

This southern sector exhibits, from west to east, the remnants of an Ordovician magmatic arc associated with a coeval backarc basin developed on the western margin of Pampia. The central and eastern parts have isolated patches of mafic and ultramafic rocks of Late Proterozoic to Early Paleozoic ages that may represent a belt of oceanic crust of variable affinities.

7. The orogenic systems developed in Pampia

The late-Neoproterozoic to early Paleozoic orogenic systems from central-northwestern Argentine developed within the Pampia cratonic block comprise two distinctive orogens, which were active during and soon after the amalgamation of Western Gondwana (Cawood, 2005; Rapela et al., 2007; Ramos, 2009a). The Pampean orogeny was developed along the eastern and north-western margin of the present Sierras Pampeanas, while the Famatinian orogen was developed along the western flank of the Pampia cratonic block.

7.1. Pampean Orogen

The first stage in the evolution of the orogenic system in central-northwestern Argentina is known as the Pampean orogeny. This orogeny comprises the Puncoviscana belt in northwestern Argentina preserved at upper crustal levels. This orogen is represented by thick and tightly folded sedimentary sequences deposited in a platform environment (Omarini et al., 2008), in the late Neoproterozoic-Early Cambrian between 800 and 530 Ma (Aceñolaza and Toselli, 1981; Mángano and Buatois, 2004). These sequences are intruded by granitoids of the Tilcaric magmatic arc between 550 and 530 Ma (Omarini et al., 1999). At present the fault-bounded remnants of the Pampean orogeny in this sector comprise a north-trending belt next to the Andean foreland along the sub-Andean ranges and Eastern Cordillera.

Another orogen is developed in the eastern sector of the Sierras Pampeanas, exposed in the Sierra Norte and its extension in the Sierras de Ambargasta and Sumampa (northern domain), and in the Sierra Chica and Sierra Grande of Córdoba (southern domain of Fig. 5).

The southern domain is formed by a series of polideformed basement exposures of metamorphic rocks of Neoproterozoic to Cambrian age, imbricated by contractional ductile shear zones of probably Ordovician-Silurian age and Devonian-Carboniferous age, emplaced by Paleozoic granitoids (Bonalumi, 1988; Kraemer et al., 1995; Baldo et al., 1996; Rapela et al., 1998; Martino, 2003; Simpson et al., 2003). The old structure is mainly north-trending, and the different blocks are now tilted to the east by a series of west-verging Andean faults, that in many cases reactivated the Paleozoic and older ductile shear zones. The highest-grade rocks mainly in granulite facies conditions are represented by migmatites and S-Type granitoids forming a central migmatitic belt. This belt is north-northwest-trending, 140 km long and 40 km wide, and is truncated by the 40 km wide Achala Devonian batholith, whose major axis is NNE oriented (Fig. 5). This migmatitic belt has at both ends granulites: to the northwest the San Carlos massif (>1500 km^2) and to the southeast the Yacanto Group (∼1600 km^2). The maximum exhumation point with $P = 8$ kb and $T = 800\,^{\circ}C$ is indicated in Fig. 5.

The northern domain constitutes a large block with lower relief, with north-northeast-trending structures, and is formed by Neoproterozoic-Cambrian I-type calc-alkaline granitoids (Bonalumi, 1988; Lira et al., 1997), which host large pendants of metamorphic rocks. These intrusions, named collectively as the Sierra Norte-Ambargasta Batholith, ranging in age 555–525 Ma (Rapela et al., 1998; Schwartz et al., 2008), are related to a magmatic arc that closed the Pampean-Paraguay orogenic cycle, with a series of acidic, mesosilicic and lamphrophyric hypabyssal rocks (O'Leary et al., 2009) and polymetallic hydrothermal systems

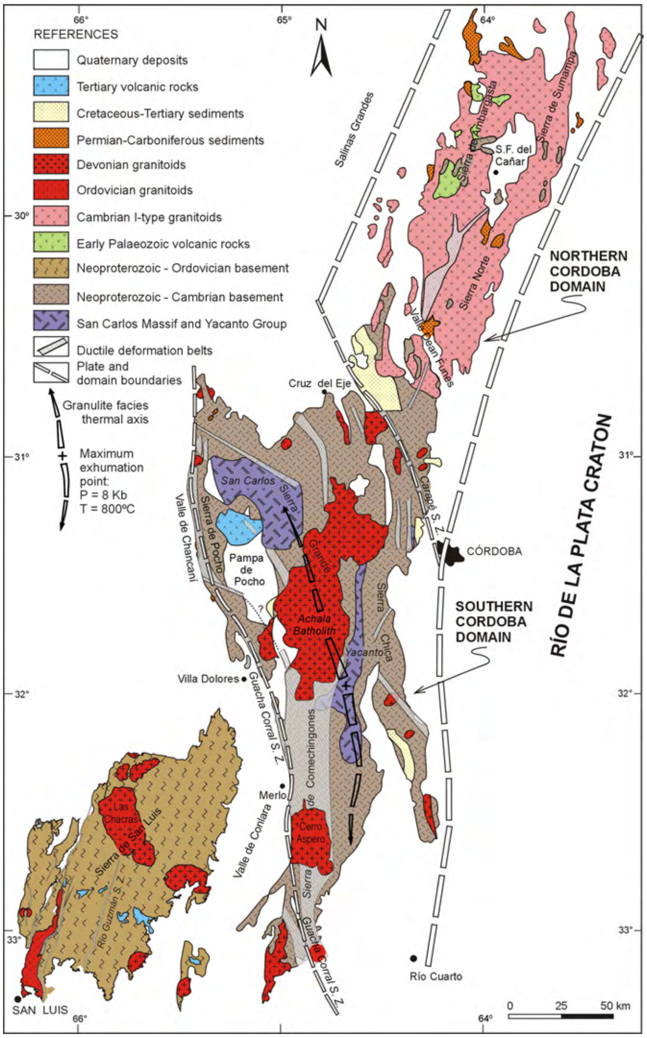

Fig. 5. Main geological features of the Pampean orogen of Córdoba (based on Martino (2003)). Note the two discrete domains of the Pampean orogen of Córdoba, where in the northern Neoproterozoic-Early Cambrian igneous rocks are dominant contrasting with the southern domain characterized by Cambrian metamorphism.

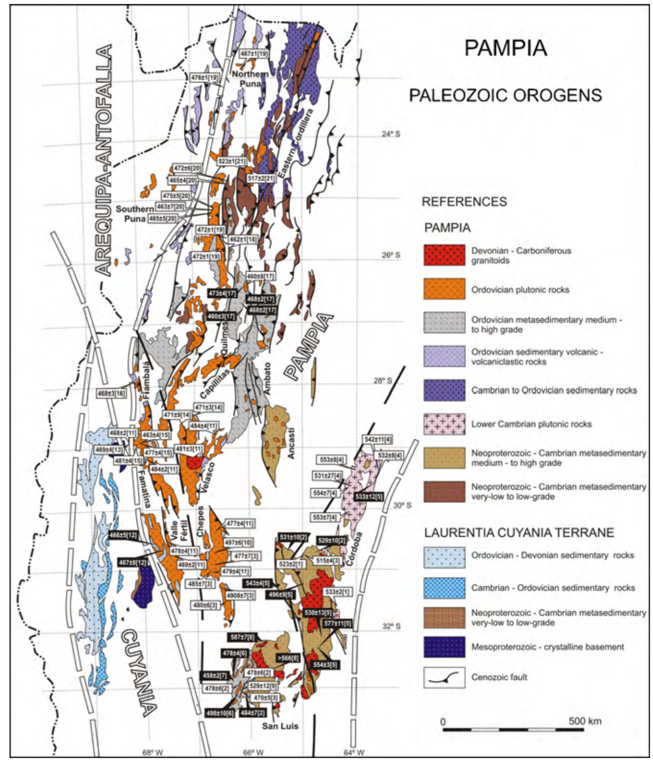

Fig. 6. Simplified geological map showing the distribution of pre-Carboniferous igneous, metamorphic and sedimentary sequences from central-northwestern Argentina modified after Vujovich and Ramos (1999), Steenken et al. (2004, 2006), and Hongn and Riller (2007). The crystallization ages for Paleozoic granitoids and metamorphic rocks are shown on white and black boxes, respectively. The original source of zircon and monazite dating are as follows: [1] Rapela et al. (1998); [2] Sims et al. (1998); [3] Stuart-Smith et al. (1999); [4] Schwartz et al. (2008); [5] Siegesmund et al. (2009); [6] Steenken et al. (2006); [7] González et al. (2004); [8] Drobe et al. (2009); [9] Söllner et al. (2000); [10] Pankhurst et al. (1998); [11] Pankhurst et al. (1998); [12] Rapela et al. (2001); [13] Dahlquist et al. (2007); [14] Báez et al. (2008); [15] Dahlquist et al. (2008); [16] Fanning et al. (2004); [17] Büttner et al. (2005); [18] Lork et al. (1989); [19] Lork and Bahlburg (1993); [20] Viramonte et al. (2007); [21] Hongn et al. (2009).

(Millone, 2004). The last fluid-rock interaction was modeled by Lira et al. (2009) for a wide region that includes the Eastern Sierras Pampeanas. The magmatic activity finished in the Late Cambrian-Early Ordovician with the emplacement of the Oncán porphyritic rhyolites (Rapela et al., 1991, 494 ± 11 Ma). These volcanic rocks are unconformably emplaced on the deformed basement and yielded SHRIMP U–Pb zircon crystallization ages of 512.6 ± 3.5 Ma. A last thermal effect dated at 481 ± 1.5 Ma indicates that final cooling of the region occurred at the base of the Ordovician (Leal et al., 2003).

The granitoids of the Sierra Norte-Ambargasta batholiths enclose large roof-pendants of a metamorphic complex, locally metamorphosed by contact, comprising low-grade (slates, phyllites and schists), medium-grade (amphibolites, marbles and gneisses) and high-grade (migmatites and calcsilicate gneisses) rocks.

The ages of these metamorphic rocks are poorly constrained but they have been assigned to the late Precambrian, based mainly on the ages of the granitoids. These rocks are truncated by large ductile shear zones, one of them of Cambrian age and right lateral strike-slip that affects the Sierra Norte (Martino et al., 1999). Relict Phanerozoic sedimentary rocks without metamorphism are also recognized as roof-pendants or in inverted tectonic depressions.

The metamorphic rocks of Córdoba experienced at lower crustal levels strong deformation and intense Barrovian-style metamorphism during the Pampean orogeny (Martino et al., 2009). In particular, studies in deep-seated crustal levels have led to the hypothesis that the eastern Pampean orogen was built along the active margin of the Rio del La Plata craton when subduction began at ca. 550 Ma (Rapela et al., 1998, 2007; Schwartz et al., 2008). In more detail these authors showed that subduction-related magmatic activity waned at around 525 Ma and was followed by a short-lived thermo-tectonic stage (ca. 530–515 Ma) (Figs. 5 and 6), documented in the northern and southern domains (Martino et al., 2009; Drobe et al., 2009).

The Sierras de Córdoba and Santiago del Estero, based on the existing data, can be interpreted as a west facing (present coordinates) passive margin formed during Rodinia break-up by clastic sediments interfingered with carbonates and marls, associated with basic rocks. The petrological and structural data and the geochronological available ages indicate that the passive margin evolved from the Neoproterozoic to 530 Ma as part of the Pampean-Paraguay orogen (Brito Neves y Cordani, 1991; Rapela et al., 1998; Fantini et al., 1998; Brito Neves et al., 1999). The exhumation of these rocks was associated with the final stages of the Famatinian orogeny as shown by Rapela et al. (1998). Some ages between 900 and 1200 Ma may indicate an older basement in the western and northern sectors as pointed out by Cingolani and Varela (1975) and Escayola et al. (2007).

These rocks are affected by a series of shear zones that represent ductile thrusts such as the Carapé, Guacha Corral and Río Guzmán shear zones (Fig. 6). These shear zones are bounding the northern domain of Neoproterozoic-Cambrian age, the southern domain of high to medium grade metamorphism of Cambrian age, and a western domain in the Sierra de San Luis of Ordovician age (Martino, 2003). Some sectors, such as the southern end of the Sierra de Comechingones, had important reactivations in Devonian times associated with the docking of Chilenia (Otamendi et al., 2009).

7.2. Famatinian orogen

The Famatinian arc started at ca. 495 Ma when subduction was reestablished along the western boundary of Pampia, so leaving behind at the back-arc the already crystalline basement metamorphosed during the early Cambrian (Fig. 6).

The southern segment (28°–38°S Lat., present day coordinates) of the Famatinian arc was closed during the middle Ordovician (beginning at ca. 465 Ma) when a continental microplate rifted from Laurentian land masses collided against the proto-Pacific Gondwana margin (Precordillera terrane of Mpodozis and Ramos, 1990 and Thomas and Astini, 1996; Cuyania terrane of Ramos et al., 1996; Ramos, 2004; or greater Precordillera or Cuyania terrane of Finney et al., 2005; Finney, 2007).

The Famatinian arc is exposed for about 2000 km along the strike of the modern central Andes parallel to the western proposed margin of Pampia from 24° to 39°S latitudes (Figs. 1 and 5), and the transition from plutonic to volcanic Famatinian rocks can be followed over large regions in northwestern Argentina (Toselli et al., 1996; Pankhurst et al., 1998; Coira et al., 1999; Coira and Koukharky, 2002; Viramonte et al., 2007). The deepest plutonic levels of the arc are currently exposed along a roughly north-trending wide belt extended along 600 km between 28° and 33°S (Fig. 1) coinciding with the area where the Nazca plate is currently subducting at a relatively low angle under South America (Jordan et al., 1983). By contrast, Ordovician eruptive igneous rocks interbedded with sedimentary rocks are widespread over the Puna and Eastern Cordillera from NW Argentina (Coira et al., 1982, 1999; Viramonte et al., 2007) and in Sierra de Famatina between 24° and 28°S (Mannhein and Miller, 1996). Since the abrupt change in exposed paleo-depths of the Ordovician system broadly coincides with northern termination of the Cuyania terrane (Fig. 1), the collisional indentation of the latter terrane is inferred to have caused the strong exhumation of the Famatinian arc southern zone.

The Famatinian arc was largely constructed during voluminous magmatism in the early Ordovician (Coira et al., 1982; Lork and Bahlburg, 1993; Stuart-Smith et al., 1999; among others). Available crystallization ages suggest that the magmatic flux seems to have migrated westward across the arc from ca. 490 to 480 Ma in the Sierras de Córdoba, San Luis, Sierra de Chepes and Eastern Cordillera to around 470 Ma in the Famatina and Puna regions (see Fig. 6), presumably due to retreat or roll-back of the subducting slab. Magmatism also grades from more mafic (significant gabbro to granodiorite) in the west to mostly peraluminous to silicic in the east. This is a first-order regional-scale petrological feature of the Ordovician arc, where an I-type dominated plutonic belt along side of an S-type dominated belt were developed (see Toselli et al., 1996; Rossi et al., 2002). Within the Sierras de Famatina, Los Llanos-Chepes-Ulapes, and Valle Fértil-La Huerta, the predominant igneous rocks are calc-alkaline metaluminous I-type granitoids, whereas weakly or strongly peraluminous felsic granitoids appear subordinate (Toselli et al., 1996; Pankhurst et al., 1998; Dahlquist et al., 2008; Otamendi et al., 2009). The opposite case occurs in other ranges among which Sierras of Fiambalá, Capillita, Zapata and, in part, Velasco are outstanding examples (Toselli et al., 1996; Rossi et al., 2002).

At upper crustal levels, several studies have also revealed the existence of two submeridian magmatic arc belts along the Famatina and the Puna (Coira et al., 1982, 1999; Coira and Koukharky, 2002). On the eastern side of the magmatic arc, the belt is called the eruptive belt of the eastern Puna (Méndez et al., 1972). This belt is mostly made up by igneous rocks interbedded with submarine sedimentary sequences that either erupted as lava flows or were emplaced as subvolcanic bodies. Igneous products are dominantly silicic and subordinately basaltic, and the magmatic activity began in the Tremadocian-Arenig boundary, extending into the Middle Arenig (Coira and Koukharky, 2002). The other magmatic belt extends all over western Puna, and is also found in northern Chile. This belt mainly consists of basaltic and andesitic lavas erupted and dacitic-rhyolitic pyroclastic deposits interbedded with shallow marine sedimentary sequences (Coira et al., 1999; Coira and Koukharky, 2002; Viramonte et al., 2007) associated with granitoids (Eruptive belt of western Puna of Palma et al., 1986). Magmatic activity in this western Puna belt ended by the middle to late Arenig (Coira and Koukharky, 2002; Kleine et al., 2004; Viramonte et al., 2007). Early Ordovician plutonic rocks encompassing from silicic granites to mafic and ultramafic bodies have been found in both the eastern and western Puna belts (Koukharsky et al., 2002; Kleine et al., 2004; Hongn and Riller, 2007; Coira et al., 2009).

Integrated at regional scale, these geological data help to further refine the Ordovician crustal section, which extends from surficial volcanic rocks and associated shallow plutons in the north (Coira et al., 1999; Coira and Koukharky, 2002; Kleine et al., 2004; Viramonte et al., 2007; Hongn and Riller, 2007; Hongn et al., 2009) to a deep-seated plutonic root in the central section (DeBari, 1994; Grisson et al., 1998; Otamendi et al., 2009). The Early Ordovician volcanic complex represents, in northwestern Argentina, the shallowest igneous rocks interfingered with coeval sedimentary sequences (Coira et al., 1999; Viramonte et al., 2007). From southern Puna to the northern Sierras Pampeanas and at paleo-depths less than ca. 15 km, the wall-rocks of the Ordovician plutonic batholiths are metamorphosed siliciclastic with subordinate carbonates sedimentary and volcanic sequences (Caminos, 1979; Toselli et al., 1996; Mannhein and Miller, 1996; Pankhurst et al., 1998; Büttner et al., 2005; Rossi et al., 2002). Widespread partial to almost complete melting of pelite and greywacke host rocks took place at more than 15 km paleo-dephts (>5 kbar) (e.g. Otamendi et al., 2009).

The implication of the previously described data is that the strong exhumation of the Ordovician arc to the south of 27–28° Lat. S must have resulted from the collision with the Cuyania composite terrane. This hypothesis explains the removal of overlying upper crust, uplift of plutonic roots, and the lack of Late Ordovician through Devonian sedimentation. Hence, the chief segmentation of the Famatinian arc was caused by the collision of the Cuyania terrane against the outboard of the Early Ordovician magmatic arc. This Middle Ordovician event, known as the Ocloyic orogeny, controlled the rapid and intensive exhumation of the Sierras Pampenas, leaving to the north a more intact crustal section of the arc preserved in the upper crustal levels in NW Argentina.

8. Discussion

The analyzed data show the existence of a large basement sialic block that collided with the Amazonia craton to generate the Sunsás orogen during Mesoproterozoic times. The western margin of this block has evidence of a pre-Puncoviscana Formation basement, which controlled the shallow water sedimentation of this unit during Neoproterozoic times. The age of this basement is inferred by the Grenville-age frequency peaks of the detrital zircons of Puncoviscana Formation (Adams et al., 2008, 2009). Previous interpretations assumed that the depositional environment was characterized by deep clastic wedges deposited directly on oceanic crust (Ramos, 1988), but new evidence shows that most of the sediments represent prodeltaic turbidites and tidalites of shallow water deposition (Omarini et al., 2008). This implies that a continental basement older than ~800 Ma, the accepted age of the base of Puncoviscana Formation, lay under the Puncoviscana basin.

Based on the frequent and sometimes dominant peaks of detrital zircons of Grenville-age along the western margin of Argentina, some authors have proposed a Mesoproterozoic belt developed along this margin as far south as the contact with Patagonia (Santos et al., 2008; Chernicoff et al., 2009b; Ramos, 2009b). This belt, although of the same age as the Grenville-age basement of Cuyania, has striking differences. The Grenville of Cuyania has isotopic and geochemical characteristics that indicate an oceanic island arc-backarc setting (Vujovich and Kay, 1998; Vujovich et al., 2004) in contrast with the reworked nature of the continental crust that characterized the orogen developed in the western margin of Pampia. The different types of Grenville-age detrital zircons have been differentiated based on the U–Pb and Lu–Hf isotope study of the accretionary prism of Chile, as well as the Guarguaraz collisional high pressure subduction complex bounding Cuyania (Willner et al., 2009). These data support that Pampia probably was part of the amalgamation of Rodinia, prior to the early Paleozoic collision of Cuyania.

Therefore, Amazonia, Pampia and Arequipa-Antofalla cratonic blocks were part of the Rodinia supercontinent, as already envisaged by Brito Neves et al. (1999), Kröner and Cordani (2003), among others. These cratonic blocks were separated by the Transbrasiliano lineament from the Sao Francisco, Paranapanema and Rio de La Plata cratons, which have distinct Mesoproterozoic history as proposed by Cordani et al. (2009). Partial evidence of this Mesoproterozoic paleogeography is the result of the geochronological and isotopic analyses made in the eastern Sierras Pampeanas by Escayola et al. (2007). These authors found an oceanic Neoproterozoic realm in the present eastern margin of Cordoba, opposite to an older source of Grenville-age in the western margin. This source was also detected in Córdoba detrital zircons by Schwartz and Gromet (2004), who found a large proportion of 950–1050 Ma grains, without the older ages characteristic of the further north Brazilian Sunsás belt. If this is correct, Pampia together with Amazonia was amalgamated to Laurentia and other paleocontinents as part of Rodinia in the Mesoproterozoic. The subsequent break-up left an open oceanic margin to the present west.

The previous hypothesis is different from Rapela et al. (2007) paleogeographic model, because, for these authors, the "Western Sierras Pampeanas" terrane includes part of the Cuyania basement. However, this composite terrane is covered by a thick carbonate platform developed at paleolatitudes of near 20° during Cambrian and Early Ordovician times, in contrast with the clastic sequences of Pampia and Arequipa-Antofalla located at subpolar latitudes (Rapalini and Astini, 1998; Ramos, 2004).

Rodinia break-up separated Laurentia and other paleocontinents from Amazonia, Pampia, and Arequipa-Antofalla. The old Mesoproterozoic sutures were reactivated by extension, but Amazonia was kept as a single landmass with Arequipa and Pampia. Extension along the suture produced the Tucavaca aulacogen and the Puncoviscana basin, which toward the south opened to a proto-oceanic basin (Escayola et al., 2009). This paleogeography is inferred by the oceanic and juvenile nature of Calalaste and Pocitos exposures in northern Argentina, which indicates that the Antofalla terrane was partially separated from Pampia, as earlier proposed by Forsythe et al. (1993) on paleomagnetic grounds (see discussion in Rapalini, 2005). The closure of this small oceanic basin generated the Tilcaric magmatic arc along the Puncoviscana belt as recognized by Omarini et al. (1999).

The southern sector of the western margin was facing onto an open ocean since Late Cambrian times, and recorded subduction and a voluminous magmatic arc developed in Pampia until middle Ordovician times as described by Otamendi et al. (2009, and references there in).

The eastern margin recorded a Neoproterozoic orogen, named as the Pampean-Paraguay orogen by Brito Neves et al. (1999), that was the result of the collision of the Paranapanema craton after consumption of the Clymene ocean (Trindade et al., 2006; Tohver et al., 2010). This ocean separated the Amazonia-Pampia craton, as a single unit, from Paranapanema. Final collision of the Rio de la Plata craton against Pampia took place in the Early Cambrian during the Pampean orogeny (Rapela et al., 1998).

The early Paleozoic history of Pampia recorded a series of magmatic arcs, back-arc basins, and complex metamorphic episodes, the analysis of which is beyond the scope of the present work.

9. Concluding remarks

The development of two distinct orogens on the northern and western margins of Pampia indicates that this cratonic block was probably part of the Rodinia supercontinent. The northern orogen was associated with the eastern end of the Sunsás belt and, since the Mesoproterozoic, Pampia has remained attached to Amazonia. This provides some hard constraints to recent Proterozoic paleogeographic models that bring Pampia (or the Pampean terrane) from further south, to collide with Amazonia in latest Neoproterozoic–Early Cambrian times.

The western orogen was produced by the Mesoproterozoic amalgamation of the Arequipa-Antofalla terrane against Amazonia and Pampia, and there is only indirect evidence for its location. However, existing U–Pb and Lu–Hf isotope studies in detrital zircons clearly show two different populations. The first is from the Cuyania terrane basement, which has well-known juvenile Grenville-age zircons derived from an island arc-back arc environment (Vujovich et al., 2004), but was accreted in early Paleozoic times. The other population is characterized by Grenville-age recycled zircons, with a local continental source that was the basement of the Puncoviscana basin. This orogen continues south of the 26°S latitude as inferred by the local sources that dominate sometimes the whole detrital zircon population of the cover, as well as the inherited zircons of the magmatic rocks.

The Transbrasiliano lineament is a continental scale structure that truncates and is displaced on the eastern margin of Pampia, a sinuous suture developed as a consequence of the closure of the Clymene Ocean. This lineament seems to have been active up to early Paleozoic times, as shown by its control on the Paleozoic basins.

Although more geochronological and geophysical data are needed, there is enough support for the existence of the large cratonic block of Pampia, at present preserved between the Arequipa-Antofalla terrane and the Rio de la Plata Craton, and this should be taken into consideration in future reconstructions of Rodinia.

Acknowledgments

The present research was funded by the Ubacyt x-182 (V.A.R.); PICTR 20298/4 (J.O. and G.V.) and CONICET PIP 5437 (G.V.). The authors want to thank Drs. Umberto Cordani and Bley Brito Neves for their critical review of an early version of this manuscript.

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