The Pavón Formation as the Upper Ordovician Unit Developed in a Turbidite Sand-Rich Ramp. San Rafael Block, Mendoza, Argentina

Paulina Abre, Carlos A. Cingolani and Marcelo J. Manassero

Abstract The Pavón Formation crops out in the central-east region of the San Rafael block; it is composed of massive green-reddish-grey sandstones, wackes, quartz sandstones, siltstones and shales. The sand-dominated facies show tabular bedding with sharp contacts and scarce syndepositional deformational structures, and were deposited in a turbidite sand-rich ramp. The graptolite fauna, in particular the presence of *Climacograptus bicornis* Biozone indicates a Sandbian age (Upper Ordovician). Sandstone petrography records a stable craton or a faulted continental basement as probable source areas. Illite crystallinity index suggest anchimetamorphic conditions underwent by the sequence. Relatively high CIA values and K/Cs ratios indicate intermediate to advanced weathering. Geochemical provenance proxies display detrital compositions derived from an average upper continental crust, but relatively high abundances of compatible elements (Cr, Ni, V, Ti and Sc) along with low Th/Sc ratios suggest mixing with a less fractionated component. The Zr/Sc ratios indicate that recycling was not important. An ophiolitic source can be neglected based on Y/Ni and Cr/V ratios. Chemical analyses of detrital chromian spinels indicate that they were formed within mid-ocean ridge basalts and conti-

P. Abre (✉)
Centro Universitario de la Región Este, Universidad de la República (UdelaR),
Ruta 8 Km 282, Treinta y Tres, Uruguay
e-mail: paulinabre@yahoo.com.ar

C.A. Cingolani · M.J. Manassero
Centro de Investigaciones Geológicas, CONICET-UNLP,
Diag. 113 n. 275, CP1904 La Plata, Argentina
e-mail: carloscingolani@yahoo.com

M.J. Manassero
e-mail: mj.manassero@gmail.com

C.A. Cingolani
Centro de Investigaciones Geológicas (CONICET-UNLP) and División Geología,
Museo de La Plata, UNLP, Paseo del Bosque s/n, B1900FWA La Plata, Argentina

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nental flood basalts. Nd model ages of Pavón sandstones scatter around 1.4 Ga, $\varepsilon_{Nd}(t)$ (t = 455 Ma) values range from −0.4 to −4.1 and $f_{Sm/Nd}$ is of −0.40 ± 0.06 on average, indicating an affinity to Grenvillian-age crust. Detrital zircon grains dated confirmed a main Mesoproterozoic source (with peaks at 1.1 and 1.4 Ga), with subordinated inputs from Neoproterozoic and Paleoproterozoic crystalline rocks. The complete provenance dataset suggest the basement of the San Rafael block (Cerro La Ventana Formation) as the main source of detritus, but derivation from the Western Pampeanas Ranges was also probable. The siliciclastic sequence was deposited in a foreland basin at latitude of around 26°S, and linked to the accretion of the Cuyania terrane towards west of Gondwana; this accretion caused uplift by thrusting of the Mesoproterozoic crust to the east at *ca*. 460 Ma.

Keywords Geochemistry · Isotope geochemistry · Detrital zircon dating · Provenance · Paleomagnetism · Ordovician · Cuyania terrane

1 Introduction and Geological Setting

The Pavón Formation (Holmberg 1948 *emend.* Cuerda and Cingolani 1998) crops out at the eastern slope of the Cerro Bola hill, in the central region of the San Rafael Block, (Mendoza province, central Argentina; Fig. 1a–c). It is a sandy marine turbidite 700 m thick siliciclastic unit trending NW–SE for 3.5 km and with a maximum width of 1.2 km. It is intruded by rhyolites of Permian–Triassic age and partially covered by Permian volcaniclastic rocks.

The sequence is composed of an alternate green, reddish-grey massive arenites (either wackes or quartz-feldspathic arenites) and siltstones and minor black shales. Within black shales and siltstones a rich graptolite fauna was found and date the unit as Sandbian (Early Caradoc; Cuerda and Cingolani 1998). Sedimentary tractive structures are absent (Manassero et al. 1999). The sequence is gently folded forming a large anticline with an axe plunging 15° towards north; the eastern homoclinal flank has a strike of N170°/30–50°E. The central part of the homoclinal is folded and faulted (Cingolani et al. 1999). The western flank is intruded by a rhyolitic laccolith known as Cerro Bola hill (Fig. 2).

The illite crystallinity values measured by X-Ray diffraction in shales using international standards suggest anchimetamorphic grade conditions, confirmed by cleavage development, deformation and siliceous recrystallization (Cuerda and Cingolani 1998). Dykes and bedded intrusives of rhyolitic composition (2–3 m thick) as well as thin hydrothermal quartz veins are common (Manassero et al. 1999). It is not in contact with the Ponón Trehué Formation (Darriwilian to Sandbian; Abre et al. this volume), and the base of the unit is not exposed.

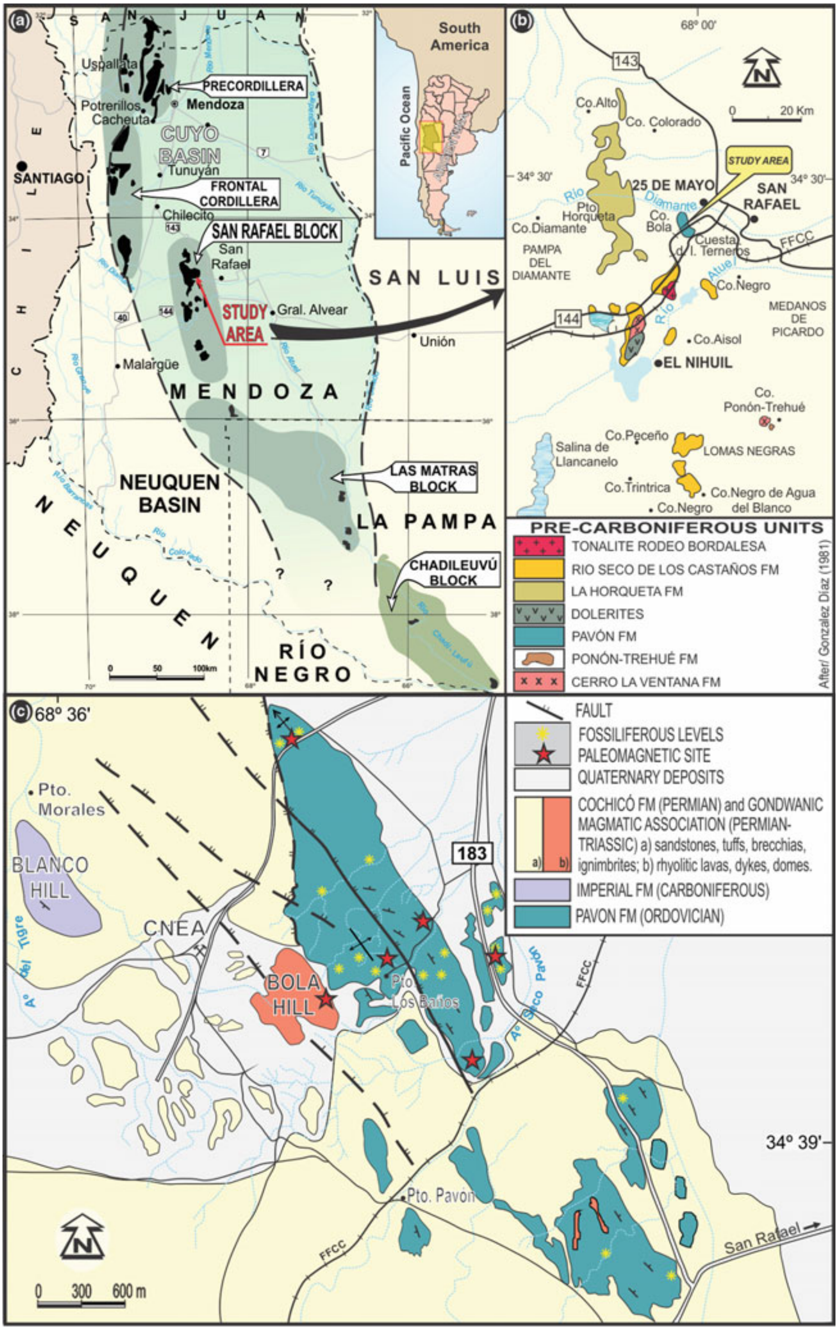

Fig. 1 **a** Location of the San Rafael Block in central-western Mendoza Province, western Argentina. **b** Sketch map showing outcrops of pre-Carboniferous rocks within the San Rafael block after González Díaz (1981). **c** The Pavón Formation develops on the eastern slope of the Cerro Bola; the studied geological sections as well as the paleomagnetic sampling sites are denoted. Modified from Cingolani et al. (2003)

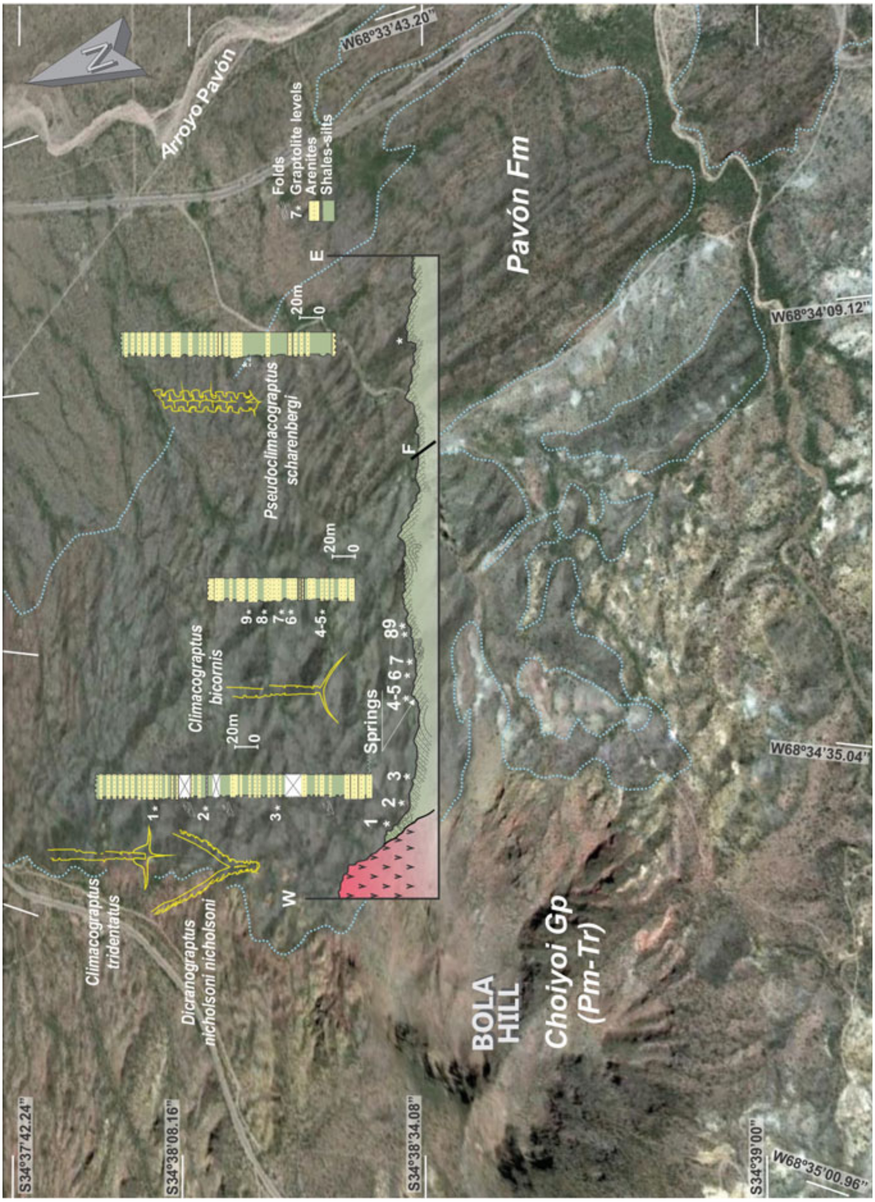

Fig. 2 Satellite image of the Bola Hill region showing the main outcrops of the Pavón Fm. The W–E section along the Baños (Springs) creek showing the Gondwanian tectonic vergence and the stratigraphic columns are based on Cuerda and Cingolani (1998). Some relevant graptolites are represented

Detailed stratigraphical, petrographical, biostratigraphical, paleomagnetic and provenance studies (including geochemistry, heavy minerals, Sm–Nd and U–Pb detrital zircon dating) were carried out on this unit, to gain insights on the tectonic evolution of the proto-Andean Gondwana margin during the Ordovician. A review of all the information available is here presented.

2 Stratigraphy and Paleontological Record

The unit is characterized by alternate arenites and pelites in tabular strata, laterally continuous, with sharp contacts (Fig. 3a–d). The arenites are mainly moderately sorted wackes although low matrix arenites are also present, indicating association of turbidite and granular flows; substratal sedimentary structures such as flow casts, load casts and ripples are common, as well as lamination and current-ripples. All these characteristics point to turbidite deposits within a sand-rich ramp, with predominance of sandy-facies proximal regarding system feeding source (Manassero et al. 1999). The deposition of the unit occurred within a progradational system, showing rather vertical than lateral facial changes indicating sedimentary transport through a linear trough. The coarser grain size recorded is very coarse arenite. In a broad sense, it is a coarsening and thickening upwards sequence; the arenite levels

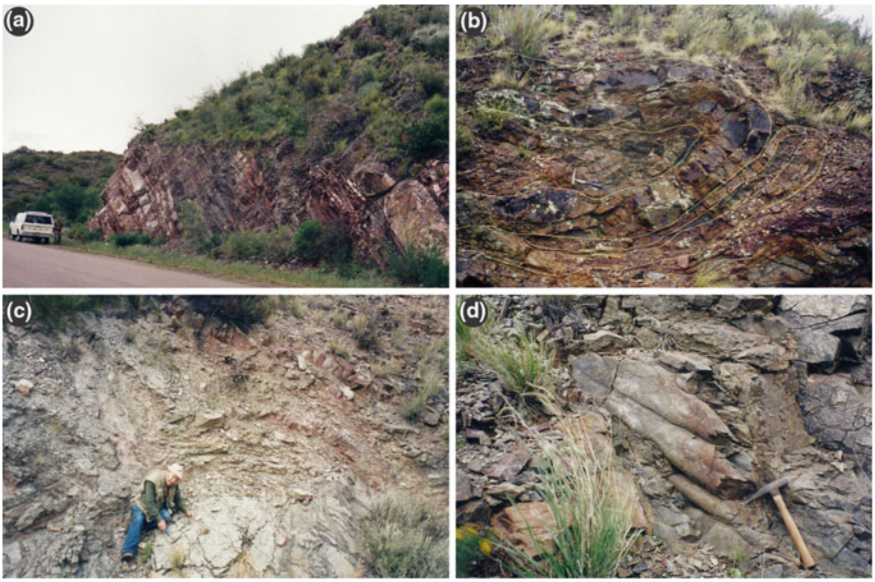

Fig. 3 **a** General view of outcrops on the northern section of the Pavón Fm. Coarsening and thickening upwards trends with beds reaching up to 1 m towards the top can be observed. **b** and **c** Show the folding of the unit with east vergence as a consequence of the 'Chanic tectonic phase'. **d** Substratal structures are a common feature

are 0.2–2 m thick, being the commonest the less than 0.5 m thick levels, but strata showing thickness of up to 12 m were also reported (Manassero et al. 1999).

Paleocurrents indicate towards west (N240°–310°) depositional direction. According to Manassero et al. (1999) five lithofacies can be identified: black shales with graptolites, finely stratified arenites and pelites, green siltstones, medium stratified arenites and coarse stratified arenites.

Graptolites found within black shales were mentioned by Marquat and Menéndez (1985), and then described by Cuerda and Cingolani (1998) and Cuerda et al. (1998). They are scarce and poorly preserved and rhabdosomes show evidence of deformation. The 25 different taxa belong to the families of Glossograptidae, Nemagraptidae, Dicranograptidae, Diplograptidae, Orthograptidae, Lasiograptidae and Retiolitidae. Particularly important regarding age determination is the presence of *Climacograptus bicornis, Climacograptus tridentatus*, since they point to Sandbian age (Fig. 2). From base to top, the graptolites are arranged in three assemblages based on which the unit was correlated to Empozada, Portezuelo del Tontal, Sierra de la Invernada, Las Plantas and La Cantera Formations of the Precordillera *s.s.* (Cuyania terrane), as well as to the Lagunitas Formation in the eastern flank of the Frontal Cordillera (Tickyj et al. 2009).

3 Petrography

A total of 43 samples of sandstones and siltstones were analyzed. Under the microscope arenites show grain sizes ranging from very fine to medium, are moderately to poorly selected and show subangular clasts with low sphericity (Manassero et al. 1999; Cingolani et al. 2003). Main mineralogical constituents are: monocrystalline (dominant) and polycrystalline quartz. K-feldspar (microcline and orthose) are commonly altered to sericite, chlorite, vermicular kaolinite and other clay-minerals. Plagioclases are scarce. Lithoclasts recorded were derived from low grade metamorphic rocks, as well as from sedimentary (chert, chalcedony and pelites) and igneous rocks (Manassero et al. 1999; Cingolani et al. 2003). Following Dott (1964), samples are classified as feldspathic and quartz wackes, with matrix content ranging from 15 to 30%. Their characteristics as well as the determination of tectonic setting using discrimination ternary diagrams based on petrographical data allowed Manassero et al. (1999) to determine a provenance from crustal plutonic and metamorphic rocks, more probably from a stable craton or a faulted continental basement. Illite crystallinity index indicate anchimetamorphic conditions for the finest rocks of the sequence, which are in turn composed mainly of illite and chlorite, with subordinated smectite and kaolinite (Manassero et al. 1999).

4 Heavy Minerals

Analysis of detrital heavy minerals is a reliable tool to constrain the composition of the sources, particularly if petrography, geochemistry and Nd isotopes had shown source mixing (Mange and Maurer 1992), as it is the case for the Pavón Formation (Cingolani et al. 2003). The detrital heavy mineral assemblages found in five wacke samples are predominantly composed of zircon, spinel and rutile in order of abundance; less common are apatite and sphene (Abre et al. 2003, 2005; Abre 2007). Spinel grains contained in sedimentary rocks can provide important information regarding source areas closely related to the depositional site, via geochemical analysis of individual grains (Dick and Bullen 1984; Barnes and Roeder 2001; Kamenetsky et al. 2001).

The spinels occur in fine grained, poor to moderately sorted wackes of the Pavón Formation. The Cr concentration of the unit varies between 65 and 292 ppm and has an average of 139 ppm (Cingolani et al. 2003), which represents an enrichment compared with the average Cr concentration of wackes (Cr = 67 ppm) and shales (Cr = 88 ppm) according to Taylor and McLennan (1985).

Based on chemical composition of the separated chromian spinels two groups of grains were identified (Fig. 4). These groups are morphologically indistinguishable, showing sizes ranging from 40 to 110 μm with an average of 60 μm for both, and the proportion of subhedral, anhedral and euhedral grains are also equal in both groups. They do not show any visible zonation, intergrowth or inclusions and are black in colour. No compositional variations were determined, as there is no

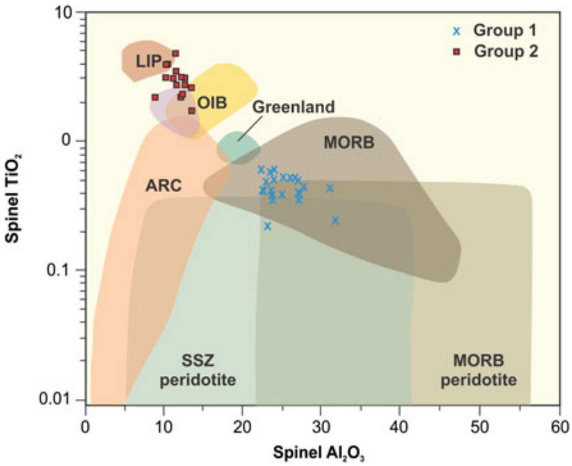

Fig. 4 Relationship between spinel contents of TiO_2 versus Al_2O_3 showing Pavón Formation samples plotting within the MORB field (Group 1) or clustering between the LIP and OIB fields (Group 2). The *purple area* represents data from the Don Braulio Formation (from Abre 2007). *SSZ* supra-subduction zone; *OIB* ocean island basalts; *LIP* large igneous provinces; *MORB* mid-ocean ridge basalt. Modified from Abre et al. (2009)

difference between core and rim, neither intergrowths nor exsolution of other mineral species (Abre 2007; Abre et al. 2009).

Group 1 (60% of total grains) has a range in Cr# = Cr/(Cr + Al) between 0.47 and 0.58, a Mg# = Mg/(Mg + Fe^{2+}) atomic ratio ranging from 0.50 to 0.80, TiO_2 concentrations of less than 0.60% and Fe^{3+}# ratio (Fe^{3+}# = Fe^{3+}/(Cr + Al + Fe^{3+})) ranging from 0.04 to 0.11, while MnO, V_2O_5, NiO and ZnO concentrations are very low. Group 2 (40% of the spinel grains) has a range in Cr# between 0.69 and 0.73, a Mg# ranging from 0.21 to 0.50, TiO_2 concentrations are very high (between 1.7 and 4.7%) and Fe^{3+}# ratios are between 0.09 and 0.19; MnO, V_2O_5, NiO and ZnO concentrations are also very low (Abre 2007; Abre et al. 2009).

Using several tectonic setting discriminatory diagrams based on Fe^{3+}#, Fe^{2+}#, TiO_2, Cr, Al_2O_3 and their ratios (Barnes and Roeder 2001; Kamenetsky et al. 2001) deduced that Group 1 is related to ocean floor basalts from a mid-ocean ridge, while Group 2 was derived from flood basalts in an oceanic or continental intraplate setting (Fig. 4; Abre 2007; Abre et al. 2009). Unfortunately, the source rocks of these spinels were yet not identified, but mafic rocks from the Western Precordillera belt, particularly its extension within the San Rafael Block (namely the Mesoproterozoic section of the El Nihuil Mafic Unit; Cingolani et al. this volume) remain as the more probable sources. Chromian spinels from the Don Braulio Formation (Precordillera *s.s.*; Cuyania terrane) had an origin in ocean island basalts, being therefore different to those comprised in the Pavón Formation (Fig. 4; Abre et al. 2006; Abre 2007).

5 Whole-Rock Geochemistry

Differential concentration of elements rather in mafic (Sc, Cr, Co) than felsic (La, Th) rocks, REE (rare earth elements) patterns and the character of the Eu-anomaly have been used for provenance and tectonic determinations (Taylor and McLennan 1985). The use of geochemical analyses for provenance determination could be particularly useful in the case of wackes. However, since the signature of the source rock may be modified by weathering, hydraulic sorting and diagenesis, it is then necessary to determine the effects that these factors had on the geochemical composition of sedimentary rocks (Nesbitt and Young 1982; Cox et al. 1995). Geochemical analyses of the Pavón Formation were presented by Cingolani et al. (2003).

Samples from the Pavón Formation have SiO_2 concentrations ranging from 61.1 to 91.7%, Al_2O_3 is between 4.2 and 12.7%, Fe_2O_3 ranges from 0.4 to 9%, CaO and Na_2O are present in low concentrations (0.42 and 0.74% on average, respectively), whereas K_2O is between 0.84 and 3.72%.

Weathering: CIA (Chemical Index of Alteration) values range from 67 to 85 indicating intermediate to advanced weathering conditions and samples plotted in an ACNK diagram follow a general weathering trend parallel to the A–CN boundary; Potassium enrichments are not shown (Fig. 5a; Abre et al. 2011). Since Cs tends to be fixed in weathering profiles whereas K tends to be lost in solution,

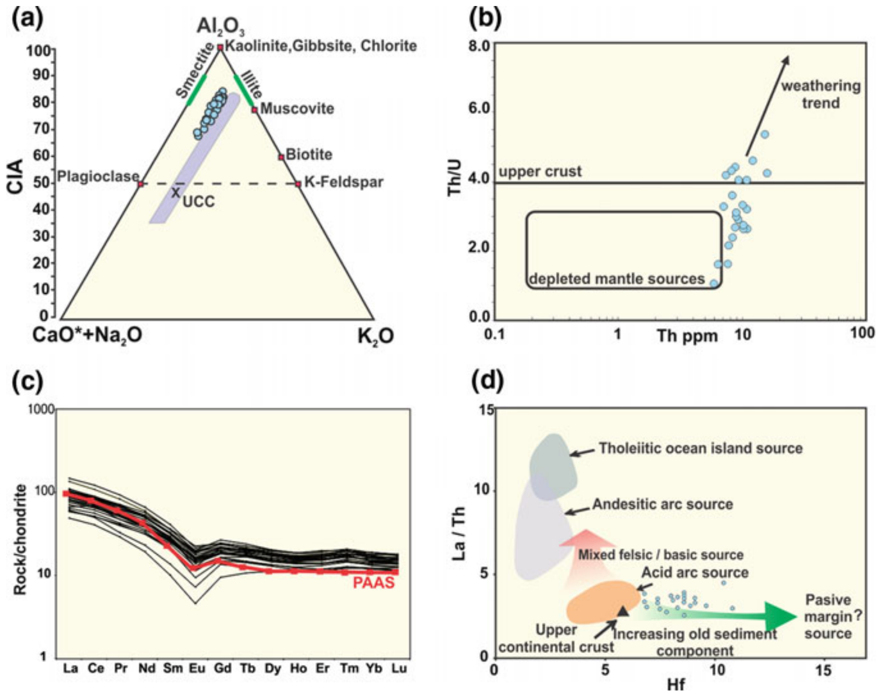

Fig. 5 **a** The Chemical Index of Alteration is calculated using molecular proportions as $(Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)) \times 100$, where CaO* refers to the calcium associated with silicate minerals; samples plot along a vertical array parallel to the expected weathering trend (field of *vertical lines*) for average upper crustal rocks. UCC values according to Taylor and McLennan (1985). **b** Th/U versus Th based on McLennan et al. (1993) showing distribution of samples from the Pavón Formation. **c** Chondrite normalized REE patterns; PAAS = post-Archaean Australian shales pattern (Nance and Taylor 1976) is draw for comparison. Eu-anomaly calculated as $Eu_N/Eu^* = Eu_N/(0.67Sm_N + 0.33Tb_N)$, where "N" denotes values normalized to chondrite. **d** La/Th versus Hf after McLennan et al. (1980); common values of the La/Th ratios for upper crust components are between 2 and 4

the K/Cs ratio is an indicator of weathering (McLennan et al. 1990); the K/Cs ratio for the Pavón Formation ranges from 1322 to 6410, with an average value of 4621 indicating strong weathering conditions (calculated from data presented in Cingolani et al. 2003).

During weathering, there is a tendency for an increase in the ratio between Th and U to greater than upper crustal igneous values of 3.5–4.0, due to the oxidation of U^{4+} to the more soluble U^{6+}. A low Th/U ratio can be a consequence of U enrichment (McLennan 1989). The Pavón Formation have Thorium concentrations below the average for the upper continental crust (9.3 ppm, with Th concentrations as low as 5.77 ppm), but a few samples are enriched (Cingolani et al. 2003). Although most of the samples are enriched in U compared with the upper continental crust (UCC), some samples are depleted (average U concentrations is of 3.2 ppm). The Th/U ratios are either below 3.5 or between 3.5 and 4, although a very few samples have high Th/U ratios of up to 5.2, pointing to weathering conditions (Fig. 5b; Abre et al. 2011).

Provenance: Average values of trace elements recorded for the Pavón Formation indicate a dominant provenance from a UCC composition, although the unit is enriched in Sc, V and Cr (14, 112 and 139 ppm on average respectively), which typically would indicate a depleted source; Cingolani et al. 2003).

Further discriminations of such mafic component could be achieved using the Y/Ni and Cr/V ratios (McLennan et al. 1993). For the Pavón Formation, the Y/Ni ratio ranges from 0.07 to 1.26 whereas the Cr/V ratio is between 0.83 and 2.5, confirming the influence of a mafic source, being represented by the detrital chromian spinels, but ruled out an ophiolitic precursor (Cingolani et al. 2003).

The chondrite normalized REE patterns for samples of the Pavón Formation (Fig. 5c) show a moderately enriched Light-REE pattern (La_N/Yb_N of about 5.7 on average), a negative Eu-anomaly (Eu_N/Eu^* ranges from 0.47 to 0.77) and a flat Heavy-REE (Tb_N/Yb_N of 1.2 on average). The samples are enriched in Heavy-REE compared with the PAAS (Cingolani et al. 2003). The La/Th ratio falls between 2.6 and 4.6, similarly to UCC rocks, and the relationship to Hf concentrations indicate limited recycling (Fig. 5d).

The Zr/Sc and Th/Sc ratios are powerful tools to decipher different source components of sedimentary rocks (McLennan et al. 1993). The samples of the Pavón Formation have Zr/Sc ratios ranging from 11.7 to 40.1 confirming that recycling played a subordinated role, whereas the Th/Sc ratios (0.43–0.89) include low values, which clearly point to a depleted source, besides the main derivation from average UCC composition (Cingolani et al. 2003).

According to the tectonic classification from Bhatia and Crook (1986), samples of the Pavón Formation plot within the continental island arc and the active continental margin fields (Cingolani et al. 2003).

6 Isotope Geochemistry

Sm–Nd: The grade of fractionation and the average crustal residence time of the detrital mix can be determined using the Sm–Nd isotope system as applied to sedimentary rocks (Nelson and DePaolo 1988; McLennan et al. 1990). Five samples of the Pavón Formation were analyzed and analytical data can be found in Cingolani et al. (2003). ε_{Nd} (t) values, where $t = 455$ Ma (depositional age) range from −0.4 and −4.1(Fig. 6), $f_{Sm/Nd}$ is between −0.34 and −0.52 (average -0.40 ± 0.06) and T_{DM} ages range from 1.1 and 1.51 Ga.

ε_{Nd} (*t*) values obtained are neither typical of UCC nor of a juvenile input despite one sample showing a less negative ε_{Nd} (*t*) of −0.4 and a low Th/Sc ratio (0.43) which could be indicating the input from a juvenile source. The $f_{Sm/Nd}$ values could be assigned to either an old upper crust or to an arc component and generally indicate that the Sm–Nd system is not fractionated, except in the case of one sample with a $f_{Sm/Nd}$ of −0.52 (Abre 2007; Abre et al. 2011).

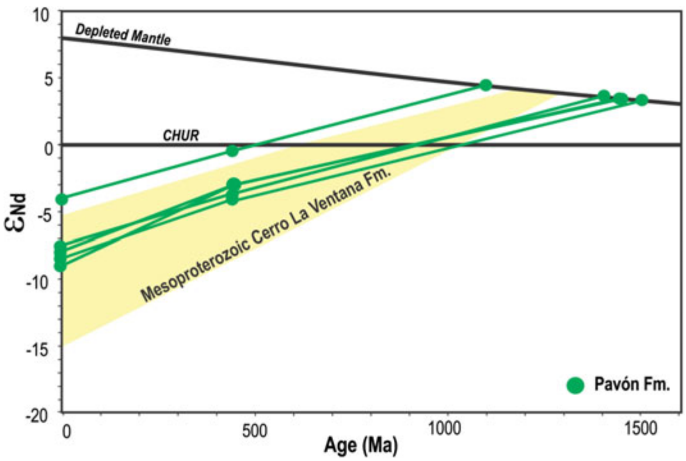

Fig. 6 ε_{Nd} versus age of the Pavón Formation and in yellow the Mesoproterozoic Cerro La Ventana area evaluated as probable source. *CHUR* Chondritic Uniform Reservoir. ε_{Nd} $(t) = \{[(^{143}Nd/^{144}Nd)\ sample\ _{(t)}/(^{143}Nd/^{144}Nd)CHUR\ _{(t)}] - 1\} \times 10{,}000$. $^{143}Nd/^{144}Nd_{CHUR}$ = 0.512638. Data from Cingolani et al. (2003)

Results presented from the five samples analyzed are consistent with a Grenvillian basement as the main source of detritus (Fig. 7; Cingolani et al. 2003), but it does not explain the −0.4 value displayed by one sample of the Pavón Formation, implying either that not all the Mesoproterozoic basement rocks were detailed studied (e.g. mafic compositions within the Cerro La Ventana Formation and gabbroic and mafic cumulates recorded within the El Nihuil Mafic Unit), or inputs from other sources. In this regard, the data available from the Western Pampeanas Ranges (e.g. Umango Range; Porcher et al. 2004; Vujovich et al. 2005; Varela et al. 2011) display positive ε_{Nd} values and point to such rocks as probable detrital sources. Furthermore, T_{DM} ages of Pavón Formation and of basement Mesoproterozoic rocks from the Cuyania terrane are comparable (Kay et al. 1996; Cingolani et al. 2003), as well as they are similar to T_{DM} ages of supracrustal Ordovician to Silurian rocks (Gleason et al. 2007; Abre 2007; Abre et al. 2012).

U–Pb detrital zircon: Another provenance approach is to determine the ages of detrital zircon grains in order to constrain the possible source rocks for the Pavón Formation basin, in particular regarding felsic to intermediate crystalline rocks. Zircons were obtained from a subfeldspathic–arenites and data and analytical techniques were presented by Abre et al. (2011).

Discrimination between igneous and metamorphic zircon grains may be achieved by measuring the Th/U ratio of single grains, since this ratio is of about 0.1 or lower for metamorphic zircons, whereas it is >0.2 or >0.5 for igneous zircons (Vavra et al. 1999; Hoskin and Schaltegger 2003). The detrital zircon dating of the Pavón Formation shows that all the zircon grains analyzed except one have Th/U ratios indicative of a magmatic origin. Such a conclusion is supported by cathodoluminescence images showing that most of the grains are subhedral and

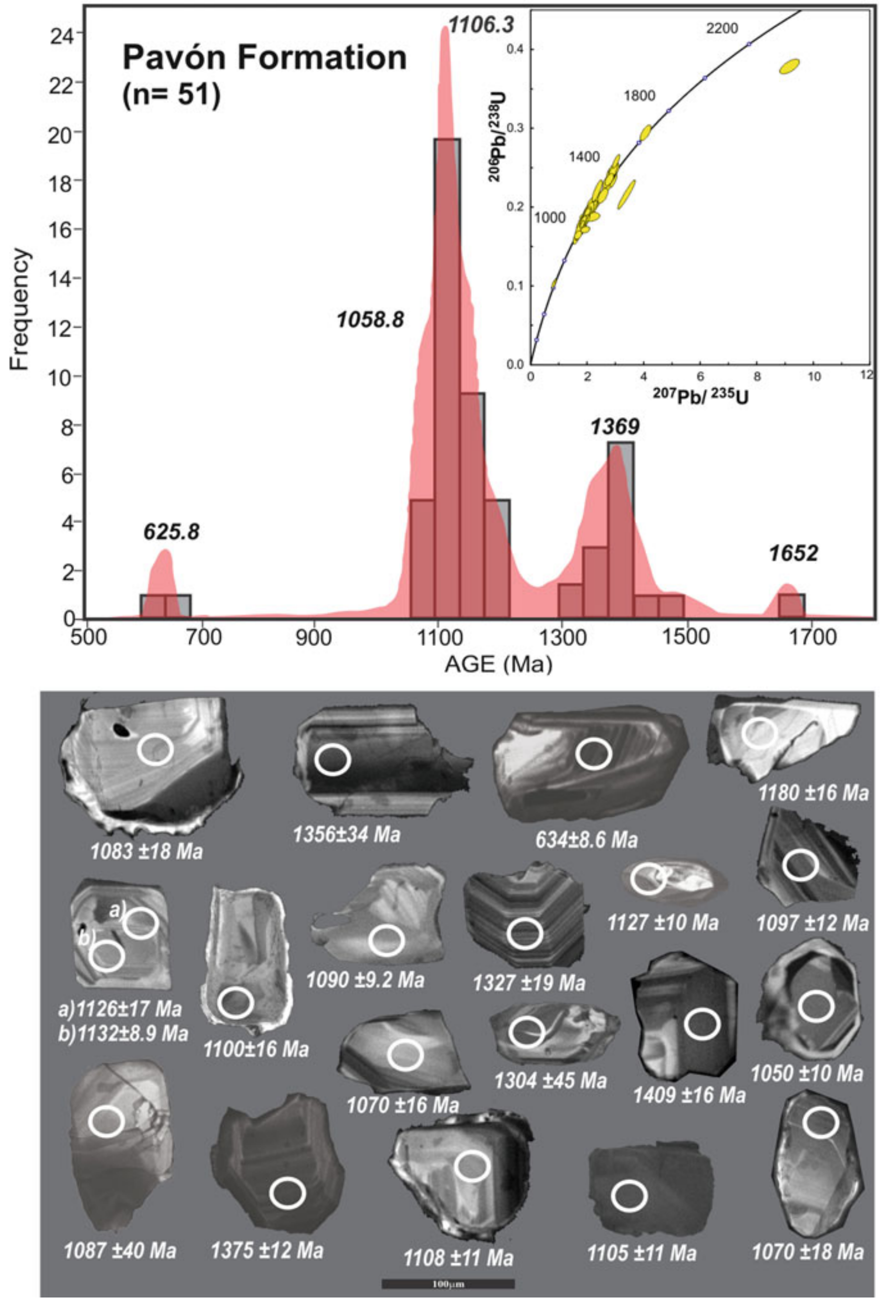

Fig. 7 U–Pb distribution of analyzed detrital zircons with probability curves for the Pavón Formation; representative cathodoluminescence microphotographs of selected zircon grains. Based on Abre et al. (2011)

display oscillatory zoning interpreted as magmatic in origin, whereas only a few have patchy metamorphic zoning (Fig. 7; Abre 2007; Abre et al. 2011).

The zircon dating of the Pavón Formation (n = 53) indicate a main population between 1.0 and 1.3 Ga comprising 35 grains (about 69% of the total measured grains), a population with ages between 1.3 and 1.6 Ga which comprise 13 grains (about 25%), whereas two grains are Neoproterozoic (634 and 615 Ma) and one grain is Paleoproterozoic with an age of 1652 Ma (Abre 2007; Abre et al. 2011).

Source rocks of Mesoproterozoic age that could have provided the bulk of detrital zircons are known from several neighbouring areas, such as the basement of the Cuyania terrane (Cerro La Ventana Formation; Cingolani and Varela 1999; Cingolani et al. this volume) and the Western Pampeanas Ranges (Varela and Dalla Salda 1992; Varela et al. 1996; Pankhurst et al. 1998; Casquet et al. 2006). These probable sources also comprise rocks of Paleoproterozoic age. The Neoproterozoic zircons could be linked to the Pampean/Brazilian Orogen.

7 Paleomagnetism

Eighty-three oriented samples collected at twelve sites from the Pavón Formation were used for paleomagnetic studies (Fig. 1c; Rapalini and Cingolani 2004). After standard demagnetization techniques, two components with geologic significance were determined. (1) Component A: isolated at most sites sampled of the Pavón Formation as well as at a Permo-Triassic rhyolitic dome intruding the unit. This component is a secondary magnetization acquired in the latest Permian-Early Triassic during the widespread Choiyoi magmatic event that affected this region, since the paleomagnetic pole position is consistent with the Late Permian reference pole for South America. (2) Component B: determined at four sites (22 samples) of the Pavón Formation. It is carried either by hematite (B1) or magnetite (B2) and the presented dual polarities and the positive fold test suggests a primary detrital or early diagenetic origin, therefore this component accurately records the Earth Magnetic Field during the Sandbian (c. 455 Ma) and indicates that the sediments of the Pavón Formation were deposited at latitude of 25.7° ± 2.9°S. This Upper Ordovician paleomagnetic data record the first Cuyania terrane paleopole (Rapalini and Cingolani 2004).

This paleolatitude can be reconciled with the Gondwana reference pole by assuming a 30° clockwise rotation of the sampling localities around a vertical axis located in the study area. However, if the San Rafael block, as the southern extension of the Cuyania terrane is located close to Southeast Laurentia, paleomagnetic data agree with the Late Ordovician reference pole of Laurentia, particularly if a 500 km stretching is considered between the Cuyania terrane and the Ouachita Embayment along the Texas and Alabama-Oklahoma transforms faults (Rapalini and Cingolani 2004).

8 Tectonic Setting

Sedimentologic characteristics indicate deposition of sandy turbidites within a foreland basin (Manassero et al. 1999; Cingolani et al. 2003), formed during the extensional regime that followed the accretion of Cuyania terrane to Gondwana in the Middle Ordovician (Astini 2002; Cingolani et al. 2003); eastern palaeocurrents invalidate western sources (Manassero et al. 1999; Cingolani et al. 2003). Further constraints are provided by petrographical, geochemical and isotopic analyses which indicate that the sources components were dominantly unrecycled UCC and subordinately a less fractionated one. The depleted component is at least partially represented by detrital spinels derived from MORB and flood basalts in oceanic or continental intraplate settings, although the source rocks of such detrital grains were not identified (Abre et al. 2009). The age of the main sources is Mesoproterozoic, with minor contributions from Paleoproterozoic and Neoproterozoic sources.

Evidence presented link the Mesoproterozoic Cerro La Ventana Formation as a provenance component to the Ponón Trehué Formation (Darriwilian to Sandbian) of the San Rafael Block (Abre et al. 2011; Abre et al. this volume). Such a provenance is also very likely regarding the Pavón Formation, although the current information available needs to invoke another eastern source area in order to fully explain provenance proxies of the Pavón Formation; such area is most probably the western side of the Pampia terrane (Fig. 8), since the Umango, Maz and Espinal ranges comprise rocks that could account for detrital zircon ages, Sm–Nd data and tentatively for the host rocks of detrital chromian spinels. However, a certain detrital derivation from the Mesoproterozoic rocks of the El Nihuil Mafic Unit may have also occurred; detailed studies of its gabbros and mafic cumulates are needed to further support this. The absence of an important recycling (with some exceptions) tend to ruled out sources located further afield with respect to the depositional

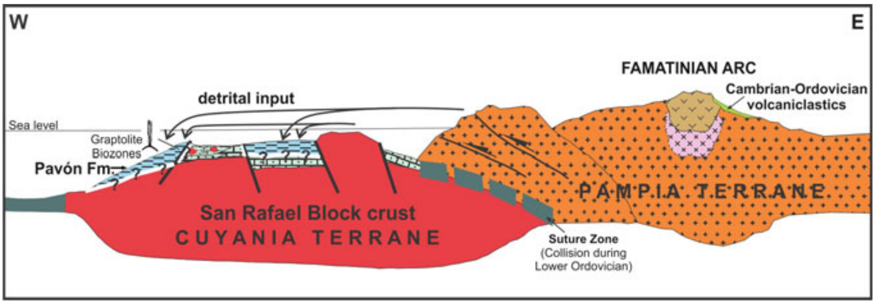

Fig. 8 Interpretative schematic cross section showing that the Ordovician Ponón Trehué Formation received an input restricted to the Cerro La Ventana Formation (see Abre et al. this volume). Progressive subsidence of the basin and deposition of the Pavón Formation during Sandbian age; the Western side of Pampia terrane was uplifted and acted as source of detrital material along with the Cuyanian basement. The Ponón Trehué and the Pavón Formations are not in contact. Modified from Abre et al. (2011)

basin. The sources identified would imply that the Cuyania terrane would have collided to Gondwana at least immediately before the beginning of the Ordovician clastic deposition (Abre et al. 2011).

9 Conclusions

Detailed bed-by-bed studies identified five lithofacies within the sand-dominated sequence of the Pavón Formation. Regular tabular bedding, sharp contacts and scarcity of flow and load casts suggest a relatively deep marine environment and deposition by gravity flows. Black shales and siltstones contain poorly preserved (deformed) graptolites which indicate a Sandbian age due to the development of the *Climacograptus bicornis* Biozone.

The petrographic analyses of the Pavón Formation showed the dominance of monocrystalline quartz and K-feldspar as well as sedimentary, metamorphic and igneous lithoclasts, which point to an UCC component and the influence of a depleted source. Such a derivation is confirmed by geochemical provenance proxies including REE distribution, Eu-anomaly, La/Th and Th/Sc ratios, as well as by heavy minerals analysis and isotope chemistry. The unit was subject to anchimetamorphism, according to Illite crystallinity data. CIA values, K/Cs and Th/U ratios indicate strong weathering. Recycling was not important, according to Zr/Sc ratios. Y/Ni and Cr/V ratios allow discarding an ophiolitic source.

Based on chemical characteristics, the detrital chromian spinel dataset is subdivided in two groups: Group 1 is characterized by intermediate Cr# values, low TiO_2, Fe^{2+}# and Fe^{3+}#, indicating a mid-ocean ridge emplacement of their initial host rocks; on the contrary, Group 2 show high TiO_2, Fe^{2+}# and Fe^{3+}#, and Cr# values of c. 0.7 suggesting an intraplate environment. El Nihuil Mafic Unit could be identified as the definite source.

The Sm–Nd isotopic characteristics of the Pavón Formation provide evidence of upper crust source materials and a depleted source; certain isotope fractionation was also detected. T_{DM} model ages and ε_{Nd} for the provenance protoliths are consistent with Mesoproterozoic source rocks such as the Cerro La Ventana Formation and the western Pampia terrane.

The detrital zircon dating indicates a main age population between 1.0 and 1.3 Ga, a second population with ages between 1.3 and 1.6 Ga, two Neoproterozoic grains and one Paleoproterozoic, confirming the source areas proposed.

Two magnetic components were determined and the one of primary origin indicate a paleomagnetic pole of around 26°S for the Sandbian record. The Pavón Formation was deposited in a foreland basin generated as a consequence of the accretion of the Cuyania terrane to the Gondwanan active margin.

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