Pre-Carboniferous Evolution of the San Rafael Block, Argentina. Implications in the SW Gondwana Margin: An Introduction

Carlos A. Cingolani

Abstract The San Rafael Block as part of the Cuyania terrane, lies eastwards of the present-day Andean Cordillera in Mendoza province and it develops south of the Nazca flat-slab subduction zone. It is a geographical region constituted by a set of rather convex elevation oriented NW–SE from Sierra de las Peñas to Cerro Nevado as the eastern Neogene volcanic arc and ending at the transitional zone known as the La Escondida mining district; as a geological province was also cited as 'Sierra Pintada'. The knowledge about this geological region started on 1891 and was continued during the twentieth century with intense regional mapping projects carried out by different Argentine institutions through which the geological background was founded. This book is dedicated to the tectonic evolution of the pre-Carboniferous units and was organized by chronological stages, in order to know the implications in the proto-Andean SW Gondwana margin, as follows: The Mesoproterozoic basement of Laurentian affinity; tectonic extension, passive margin and Cuyania terrane collisional event during the Lower Paleozoic; Silurian-Lower Devonian orogenic sedimentation, Chanic compressional phase during the Chilenia terrane accretion in the Upper Devonian-Lower Carboniferous and finally the tectonic evolution synthesis. An updated geological map compilation is also subdivided in three regions: Sierra de las Peñas, Sierra Pintada-Cerro Nevado and La Escondida transitional zone.

Keywords Gondwana · Proto-Andean margin · Paleozoic accreted terranes · Chanic tectonic phase

C.A. Cingolani (✉)
División Geología del Museo de La Plata, Centro de Investigaciones Geológicas-CONICET, Universidad Nacional de La Plata, Diag. 113 N. 275, 1904 La Plata, Argentina
e-mail: ccingola@cig.museo.unlp.edu.ar; carloscingolani@yahoo.com

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1 The San Rafael Block in the Context of Paleozoic Gondwana Margin

The southern South America Pacific Paleozoic Gondwana margin is characterized by the presence of orogenic belts oriented in a north–south direction (Ramos et al. 1986). They had been accreted to the cratonic areas during Upper Precambrian–Lower Cambrian (Pampean cycle), Cambrian–Devonian (Famatinian cycle) and Upper Devonian–Lower Carboniferous (Gondwanian cycle). The San Rafael Block is part of the Cuyania composite terrane (Ramos 2004 and references therein), it is linked to the Famatinian cycle and lies eastwards of the present-day Andean Belt (Fig. 1).

The Cuyania composite terrane comprises four sectors, which from north to south, are: Precordillera thin-skinned (partially thick-skinned) fold and thrust belt that was generated by shallow east-dipping flat-slab subduction of the Nazca plate; the Pie de Palo area with Grenvillian-age basement; the San Rafael Block and Las Matras Block (Fig. 1). The subsurface lithofacies along the Triassic 'Cuyo basin' linked the Precordillera with the San Rafael Block (Rolleri and Criado Roqué 1970; Criado Roqué and Ibáñez 1979; Ramos 2004) with an extensional subsidence sedimentary regime.

The Cuyania terrane has been considered from a stratigraphical standpoint unique to South America due to the presence of Lower Paleozoic carbonate and

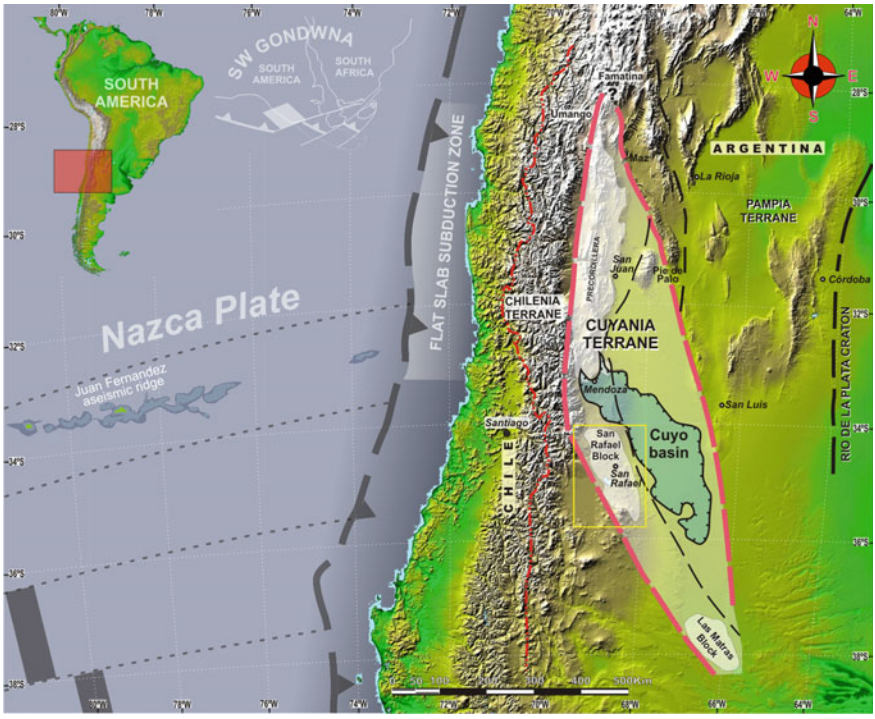

Fig. 1 Location of the San Rafael Block within the Cuyania terrane in the SW Gondwana margin

siliciclastic deposits overlying an igneous-metamorphic crust of Grenville-age (Ramos 2004; Sato et al. 2000, 2004; Varela et al. 2011); and it has been the objective of several lines of research during recent years, attempting to constrain its allochthonous or para-autochthonous origin with respect to Gondwana (Rapela et al. 1998). Some tectonic interpretations had been proposed: one explains that the terrane was detached from the southern Appalachians of Laurentia in Cambrian times, was transferred to western Gondwana during the Early to Middle Ordovician, and was amalgamated to the early proto-Andean margin by the Mid-Late Ordovician (Thomas and Astini 2003; Ramos 2004 and references therein). Other studies have claimed a continent-continent collision called 'Occidentalia terrane hyphotesis' (Dalla Salda et al. 1992), and even a para-autochthonous-to-Gondwana origin based on strike-slip displacements from the South Africa-Antarctica regions was proposed (Aceñolaza et al. 2002; Finney 2007). Geological and paleontological evidence constrain the time for the docking of Cuyania to the late Middle to Late Ordovician. The terrane deformation linked to the collision started in the Ordovician, and continued until the time of approach of the Chilenia terrane during Late Devonian, against the Pacific side (Fig. 2).

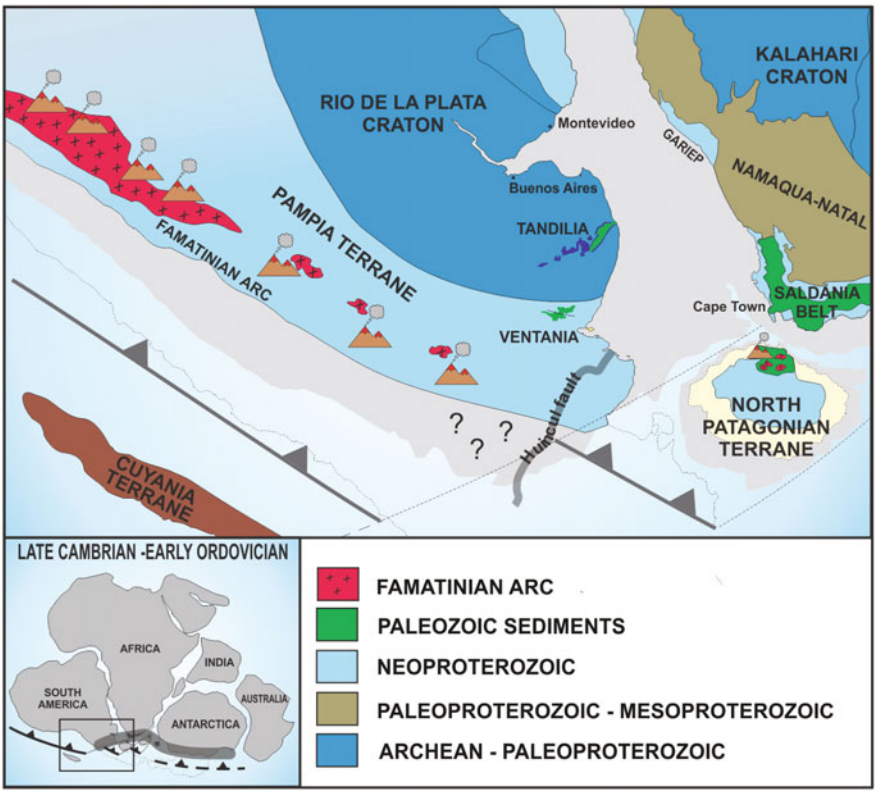

Fig. 2 Paleogeographic reconstruction of SW Gondwana region after Pankhurst et al. (2006), Gregori et al. (2008), Uriz et al. (2011) and Uriz (2014)

The San Rafael Block, as a part of Cuyania terrane, is developed south of the Andean flat-slab subduction zone as shown on Fig. 1.

2 Some Geomorphological Aspects

The variety of colours of the Upper Paleozoic volcanic and volcaniclastic rocks inspired the first denomination of the region: 'Sierra Pintada' (Burckhardt and Wehrli 1900). It is a geographical unit constituted by a set of rather convex elevations oriented approximately NW–SE (34° 14′S to 36° 10′S—68° 06′W to 69° 06′W); it rises east of the Andes from Sierra de las Peñas to Cerro Nevado (3980 m a.s.l.) as the eastern Neogene volcanic arc (Fig. 3). Two main streams cross the block in west to east direction, the Diamante and Atuel Rivers. To the north of the Río Diamante, the highest hill is Cerro de la Chilena (1775 m a.s.l.). These rivers cut across ranges and erode canyons that can reach in some places over 300 m deep. Polanski (1949, 1954) studied the geomorphological aspects of 'Mendocino territory' giving the name of '**San Rafael block**' to the mountains located southwest of the eponymous city that closely resembles the westward Frontal Cordillera for the expanded Upper Paleozoic volcaniclastic rocks. From north to south, the main positive regions are: Sierra de las Peñas, Sierra Pintada to Cerro Nevado and Agua Escondida mining district (Fig. 3). The San Rafael Block has a rich hydroelectric potential, uranium mining and tourist attractions.

3 A Geological Province

As it has been aforementioned, at the stage of the first scientific pioneers (since 1890–1945), the geological province was as named as the 'Sierra Pintada' (or Sierra Pintada System) and later as the 'San Rafael block'; afterwards, it was linked to the so-called 'Mendocino-Pampeano mobile belt' (see Criado Roqué 1969a, b, 1972) to form the geologic province 'Sanrafaelino-Pampeana' as exposed by Criado Roqué and Ibáñez (1979) which integrated the La Escondida region located southwards (Fig. 3). The San Rafael region exposed several faults and lineaments within a seismic area demonstrated by the massive earthquake of 30 May 1929, suggesting that the region is still submitted to shortening (Costa et al. 2006).

Following this criterion in the geological map compilation presented in Chapter "San Rafel Block Geological Map Compilation" it has been divided into three parts: the northern sector corresponding to the Sierra de las Peñas, the central one which comprises the Sierra Pintada-Cerro Nevado, and the southern sector which includes the Agua Escondida (or La Escondida) district. In each of these sectors we have identified places where studies on pre-Carboniferous units were done and that are

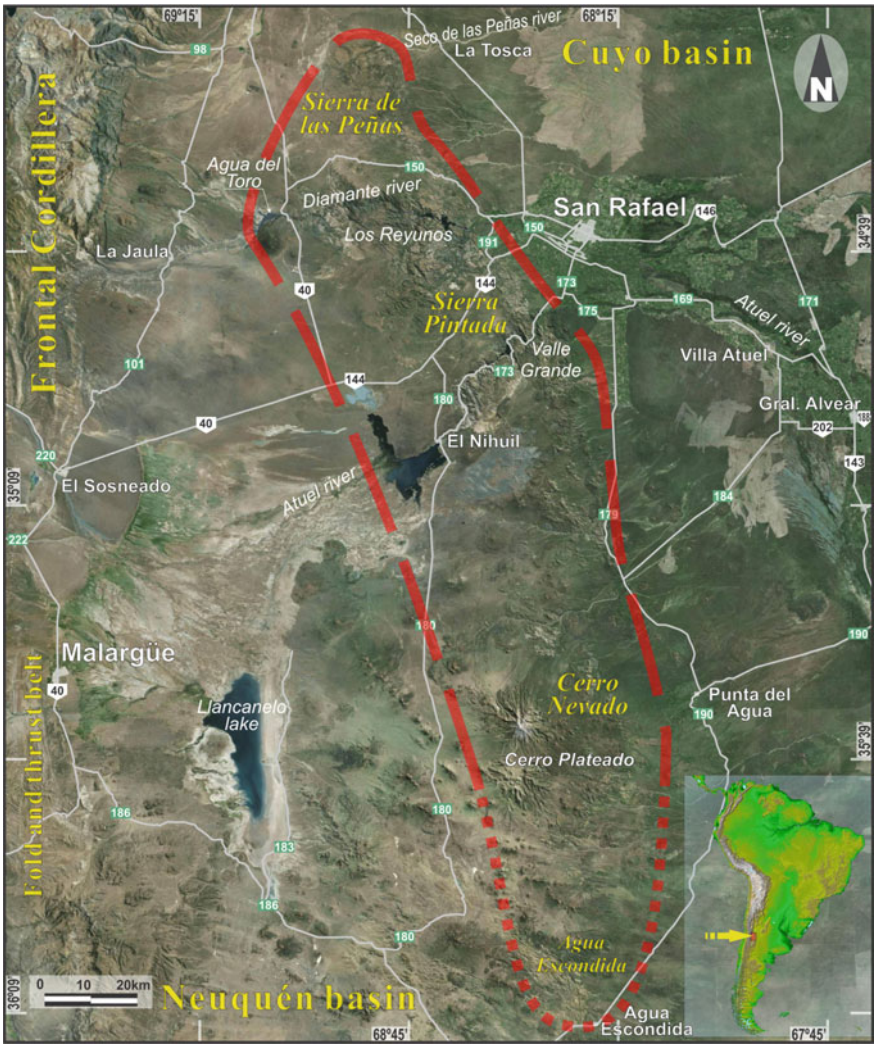

Fig. 3 Satellite image showing in *dotted red lines* the location of the San Rafael Block and the main geographic aspects as the Sierra de las Peñas, Sierra Pintada-Cerro Nevado and towards the south the transition to the Agua Escondida mining district

the aim of the herein presented book. It is important to note that throughout the text, the term San Rafael Block has been used to denote the geological province enclosing all outcrops within the Las Peñas River towards the north to the region covered by the Cenozoic volcanism of Cerro Nevado, and as a transitional zone the Agua Escondida district to the south. The Cuyo and Neuquén basins bound the San Rafael Block to the north-east and south respectively (Figs. 1 and 3).

4 Main Aspects of the Pioneer Geological Knowledge

The first geological published reference of this geological unit is due to Bodenbender (1891) who noted the presence of pre-Jurassic 'porphyry' rocks. Then Hauthal et al. (1895–96) exposed the first geographic and geological description of the 'Sierra Pintada' where Pb and Ag ore mines are present. This scientific program was prepared by Francisco P. Moreno as Director of the La Plata Museum. The topographer Lange (Lange et al. 1895) mentioned that the highest point is the Cerro Nevado (3810 m a.s.l.). Wehrli and Burkhardt (1898) and Lange, Burkhardt and Wehrli (1900) crossed the Sierra Pintada from San Rafael to Malargüe and described it as a 'small mountain range' elongated from NW to SE. Stappenbeck (1913) in an extensive travel from the Sierra Pintada to Cerro Nevado, described the main rock types and observed their relationships. In the La Estrechura (south of Río Leones, Ponón Trehué sector) he mentioned the presence of basement gneisses that supposedly were brought up to the surface by modern basalts. Later in 1934, Stappenbeck (unpublished report to the YPF Oil Company) distinguished the greywacke, mica-schist and other low-grade metamorphic rocks assigned to the Precambrian, Middle Paleozoic and what he called 'Estratos de Paganzo' which included the metasedimentary rocks of the Cerro Bola and Arroyo Pavón. He mentioned the presence of a granitic pluton related to the Las Picazas mine district near the Río Diamante, with sphalerite and galena mineralization. Wichmann (1928) mentioned basement rocks such as gneisses, granites, pegmatites, amphibolites among others as well as limestones in the Ponón Trehué area that are considered similar to those of Cerro de la Cal and Salagasta (near the city of Mendoza); he also described Carboniferous shales and sandstones Finally, he stressed the presence of an intrusive called 'diabase' near Nihuil town. Storni (1933) studied the physiographic aspects of the region west of the Sierra Pintada and north of the Río Diamante, describing an intrusive as 'quartz diorite' in schists to the NW of Agua de la Chilena. He named the region as the 'Sierra Pintada block'. Groeber (1929, 1939) worked on the volcanic and modern series of Rincón del Atuel. Keidel (1947) gave an overview of the regional geology of the San Rafael region. Padula (1949, 1951) when working for the YPF Oil Company distinguished several formations as the local 'basement' of the area. Holmberg (1948a, b) provided details from the Cerro Bola area and described the sequences as 'Estratos del Arroyo Pavón' assigned to the Upper Paleozoic. Feruglio (1946), in his work on 'Orographic Systems of Argentina', reviewed the main morphological and geological features of the region, and described the pre-Paleozoic-Paleozoic greywacke-schists and metamorphic rocks from the Sierra Pintada System and Cerro Nevado. He expressed 'this mountain can be considered as an eroded gigantic block'. Dessanti (1945) discovered the fossils within the Carboniferous El Imperial unit. After intense regional mapping in the area of the Sierra Pintada, Dessanti (1954, 1956) published the 'Hoja Geológica 27c Cerro Diamante', as a result of previous detailed and thorough field investigation. Along the present book we have used the basic stratigraphy done by Dessanti. Polanski ('Hoja Geológica 26c La

Tosca' 1964) mentioned the positive structures of the Frontal Cordillera and the San Rafael Block and describes the pre-Jurassic metasediments especially in the Los Gateados creek. To the south, the author confirms that this unit called La Horqueta is intruded by granitic stock of the Agua de la Chilena. Based on several studies González Díaz (1964) recognized the region as a morphostructural unit and named it as San Rafael Block, following Feruglio (1946) and Polanski (1964) and extended the southern boundary beyond Cerro Nevado Cenozoic volcano, to the region known as La Escondida (González Díaz 1972). He proposed the subdivision of the original 'La Horqueta Formation' into two units, a metamorphic one known as La Horqueta and the metasedimentary section called the Río Seco de los Castaños Formation (González Díaz 1981). Núñez (1976) mapped the 'Hoja Geológica 28c Nihuil', which remains as an unpublished report of the Secretaría de Minería (Buenos Aires), describing the outcrops of the Río Seco de los Castaños Formation that is composed of sandstones, greywackes and siltstones outcropping in the Lomitas Negras and around Agua del Blanco. The Loma Alta gabbros, known as 'pre-Ordovician mafic rocks' are also mentioned by the author. Then González Díaz (1964, 1972), in the geological descriptions of the San Rafael and Agua Escondida maps, distinguished a probably Devonian, Upper Paleozoic, continental Mesozoic rocks and several Cenozoic units. The region of the Cerro Nevado volcano ('Hoja Geológica 29d') was mapped by Holmberg (1973) who recognized the Cerro Las Pacas Formation as part of the metamorphic basement rocks. It was Núñez (1979) who mapped the region of Ponón-Trehué in the 'Hoja Geológica 28d Estación Soitué' and recognized the basement rocks and the carbonate Lower Paleozoic sedimentary cover with Ordovician fossils. After these pioneers works, the National Geological Survey from Argentina (SEGEMAR) organized new compilations of the geology of the San Rafael Block (see the Mendoza province Geological Map 1:500,000; Sepúlveda et al. 2001, 2007).

5 Comments on Heritage of Human History Along the San Rafael Region

The primitive inhabitants of southern Mendoza province formed several tribes spread across the plains and foothills before and after the arrival of the Spanish conquerors. Huarpes, Puelches, Pehuenches and Mapuches were bellicose and combative people, and skilled riders that knew very well the mountain passes across the Andes. Pictographs drawings on the rocks are signs that remain of those peoples. After Lagiglia (2002) they became from the 'Old Pre-Ceramic period' as hunters that lived between 15,000 and 12,000 years BP. Evidence are found near the Atuel and Diamante rivers where very rustic stone tools were found. The beginning of the 'Christian era' brought changes that influenced the 'agro-pottery' cultures, such as the addition of growing vegetables, as well as social reorganizations. During the 'Inca period', between 1450 and 1550 AD, the metallurgy acquired relevance as well as agriculture and irrigation methods. Finally, the

'Spanish Colonial period' developed after 1550: the arrival of Europeans broke the social organization of the Incas. Abundant water with two main rivers (Diamante and Atuel) permitted the settlement of several groups of original populations. Under these circumstances, the 'Fortín San Rafael del Diamante' was founded in 1805 by the Spanish Viceroy, Marqués Rafael de Sobremonte. This fortress was located near the Río Diamante, where is now the Villa 25 de Mayo. For over 70 years, this locality became a bastion of civilization, protecting those who came to the Diamante valley. Since 1875 the Italian, French and Spanish immigration dedicated to agriculture colonized the area. The Villa 25 de Mayo gradually became the 'old villa' since 1903, where the Mendoza government declared the communal authorities near the French settlement as the city of San Rafael which is one of the most important of western Argentina. The arrival of the railway from Mendoza changed the history of San Rafael. In 1903 the journal 'Los Andes' communicated the official opening of the new branch of the railroad. During 1944, it was extended southwards to connect the towns of San Rafael and Malargüe. This branch was called as 'black gold' conceived mainly for transport carbonate rocks, coal and even oil. Unfortunately the railway is unused since many years ago. Nowadays, the main activities of the region are related to its numerous wineries and olive oil production founded mainly by the French, Italian and Spanish communities.

6 Relevance of the pre-Carboniferous Geological History

The San Rafael Block shows similarities and differences compared to Cordillera Frontal and Precordillera of western Argentina; it records an interesting history of terrane accretions (Cuyania-Chilenia) during the Paleozoic in the proto-Andean Gondwana margin. As it can be seen in Fig. 4, pre-Carboniferous units of the San Rafael Block comprise: the Mesoproterozoic basement which can be correlated to other basement rocks within the Cuyania terrane; a fossiliferous Ordovician carbonate platform which unconformably overlies the basement; Ordovician siliciclastic rocks bearing interesting graptolite biozones; MORB dolerites that resemble ocean floor mafic rocks from western Precordillera; Silurian-Devonian siliciclastic units forming distinguishable sedimentary facies that record the Chanic deformation as evidence of the Chilenia terrane collision.

After more than thirty years of work experience mainly in the Lower and Middle Paleozoic geology of the Precordillera in western Argentina, we started the biostratigraphic study of the Ordovician sedimentary rocks outcropping in the Cerro Bola region (Cuerda and Cingolani 1998). In parallel, we conducted a sampling of basement outcrops of the Río Leones type-section, and their Rb-Sr results allowed us to recognize a Mesoproterozoic basement (1 Ga) similar to that found elsewhere of the Cuyania terrane (Cingolani and Varela 1999). These results and the findings of Ordovician graptolite biozones around the Cerro Bola encouraged further studies in the area. Thus, with financial support from CONICET (National Research Council) grants, sedimentological investigations (Manassero et al. 1999) and

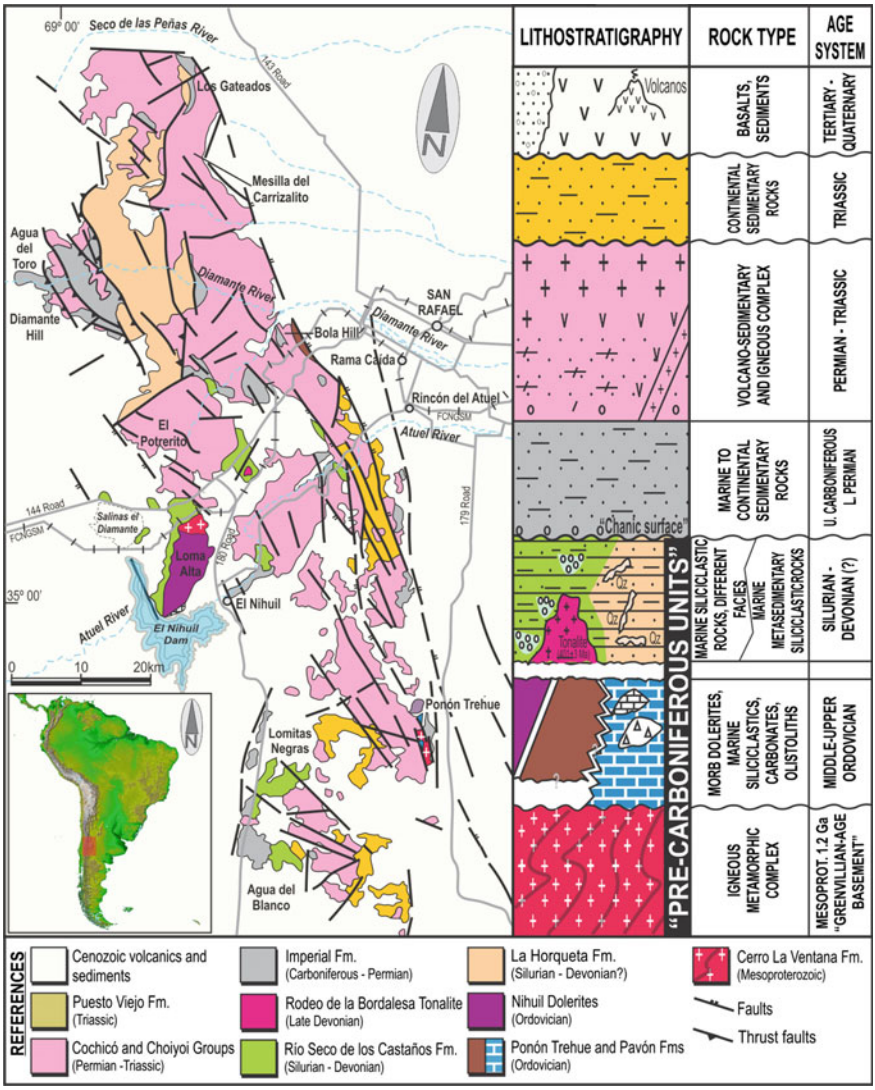

Fig. 4 Geological sketch map and stratigraphic column of the San Rafael Block showing the pre-Carboniferous units

sedimentary provenance analysis based on petrographical, geochemical and isotopic Sm–Nd data (Cingolani et al. 2003; Manassero et al. 2009) were performed. At that time, the possibility of developing a doctoral thesis on the provenance of the Ordovician sedimentary units of the Precordillera and San Rafael Block was planned. This resulted in the first detrital zircon ages presented by Abre (2007) in her Ph.D. thesis defended at the University of Johannesburg, South Africa. Interesting facts found and the geological characteristics of the region that somehow

linked a transition to the eastern sector of the Frontal Cordillera encouraged the group to apply for a grant to the Argentine National Research Agency (ANPCyT) with the aim of extending the studies to all the 'pre-Carboniferous' units of the San Rafael Block. Therefore, studies on geochemical and isotope analyses of the mafic rocks of the El Nihuil region (Cingolani et al. 2000) began with international cooperation with two laboratories: the Isotope Geology of the Federal University of Río Grande do Sul, Porto Alegre and the Geochronology Center at the University of São Paulo, Brazil; the first one under the direction of Prof. Farid Chemale Jr. and Prof. Koji Kawashita and the second with the lead of Prof. Miguel A. Stipp Basei. Several papers were published in peer-reviewed international journals as a result of these studies. Rapalini and Cingolani (2004) carried out paleomagnetic analyses of the Pavón Formation (Upper Ordovician) and defined the first Ordovician paleopole of Cuyania. Abre et al. (2009, 2011, 2012) published papers related to the Ordovician sedimentary provenance of Ponón Trehué Formation and other units from Precordillera. From 2002, the group has published partial results in several Geological Congresses, as well as in the South American Symposium on Isotope Geology and Gondwana Symposium, because interesting facts about geochemistry and isotopic geology were achieved. A complete bibliographical list can be found within each of the following chapters.

7 Book Contents

This book is mainly conceived for Earth Science professionals working in scientific research and industry, as well as university students and general interest readers. The first chapter corresponds to the Introduction and Contents of this book, whereas the following chapters deal with the pre-Carboniferous units from Mesoproterozoic basement to Silurian–Devonian sedimentary and igneous rocks. All chapters are illustrated with maps, schemes and cross-sections that constitute up-to-date proposals and several original datasets. Different sources are cited at the end of each chapter that can be used to expand particular points discussed in the book. As it is shown on Fig. 5, the book was organized by several stages as follows:

Basement of Laurentian affinity: in the second chapter C. Cingolani, M. Basei, R. Varela, E. J. Llambías, F. Chemale Jr., P. Abre, N. J. Uriz and J. Marques, provide new petro-geochemical and isotopic information to constrain the crustal evolution of the Mesoproterozoic basement. The isotopic data obtained as well as their petrological and geochemical features are reported for two main outcrops (the type-section known as Río Leones-Ponón Trehué region and a part of the El Nihuil Mafic Unit). These data are useful to discuss relationships with equivalent Mesoproterozoic units located along the Cuyania terrane in the proto-Andean Gondwana margin.

Tectonic extension, passive margin stage and collisional event: Chapter "Sedimentary Provenance Analysis of the Ordovician Ponón Trehué Formation, San Rafael Block, Mendoza-Argentina", by P. Abre, C. Cingolani and N. Uriz,

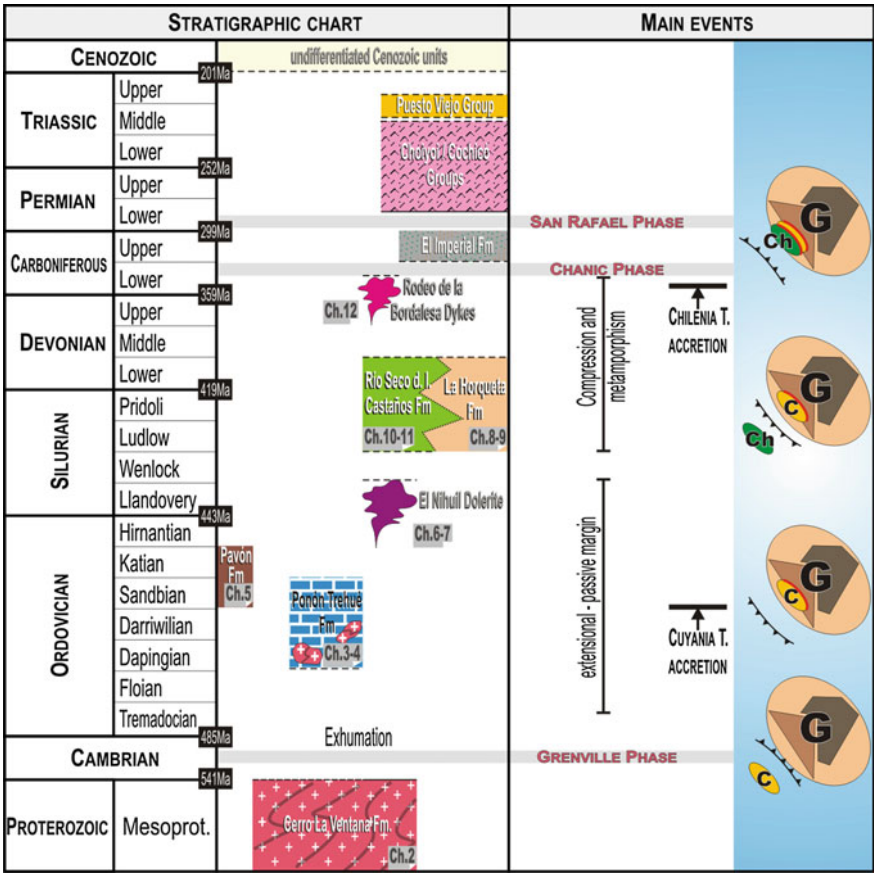

Fig. 5 The San Rafael Block studied units organized in chronostratigraphic order where the main tectonic events are represented in each chapter of the book (e.g. Chapter "The Mesoproterozoic Basement at the San Rafael Block, Mendoza Province (Argentina): Geochemical and Isotopic Age Constraints"). At the *right*, *G* SW Gondwana, *C* Cuyania terrane, *Ch* Chilenia terrane. The polarity of subduction during Paleozoic paleogeographic evolution in the proto-Andean margin is also exposed

deals with provenance analyses of the carbonate-siliciclastic Ordovician sedimentary Ponón Trehué Formation (Darriwilian to Sandbian). This is the only sequence which exhibits a direct contact with the Mesoproterozoic basement through an unconformity, not only within the San Rafael Block, but rather for the entire Cuyania terrane. On Chapter "Ordovician Conodont Biostratigraphy of the Ponón Trehué Formation, San Rafael Block, Mendoza, Argentina", by S. Heredia and A. Mestre, a review of the Middle Ordovician conodont fauna of the Ponón Trehué Formation is offered. Different genera and species of conodonts were recovered from clastic-carbonate beds and correlated to the Precordilleran units. Chapter "The Pavón Formation as the Upper Ordovician Unit Developed in a Turbidite Sand-

Rich Ramp. San Rafael Block, Mendoza, Argentina", by P. Abre, C. Cingolani and M. Manassero is dedicated to the deformed siliciclastic Pavón Formation outcropped at cerro Bola region. The graptolite fauna, in particular the presence of Climacograptus bicornis Biozone indicate a Sandbian age (Upper Ordovician). The complete provenance dataset suggests the basement of the San Rafael Block (Cerro La Ventana Formation) as the main source of debris. The siliciclastic sequence was deposited in a basin at a 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. Chapter "Lower Paleozoic 'El Nihuil Dolerites': Geochemical and Isotopic Constraints of Mafic Magmatism in an Extensional Setting of the San Rafael Block, Mendoza, Argentina", by C. Cingolani, E. J. Llambías, F. Chemale Jr., P. Abre and N. Uriz, describe new data from the 'El Nihuil Mafic Unit' that is exposed at the Loma Alta region. The authors present the petrology, geochemistry, isotope data, and determinations of emplacement conditions of the undeformed Lower Paleozoic dolerites (El Nihuil Dolerites) with a tholeiitic ocean floor basalt geochemical signature (Cingolani et al. 2000) that could represent a sliver of Cuyania-Chilenia terranes suture after the passive margin stage (Fig. 5).

Chapter "Magnetic Fabrics and Paleomagnetism of the El Nihuil Mafic Unit, San Rafael Block, Mendoza, Argentina", A. Rapalini, C. Cingolani and A. Walther offer the reconnaissance of magnetic fabric and paleomagnetic studies carried out on the El Nihuil Mafic Unit both in gabbros and dolerites. Most samples showed well-defined but scattered remanence directions which indicate that no significant paleomagnetic data can be obtained from El Nihuil Mafic Unit.

Orogenic sedimentation, Chanic compressional phase during Chilenia terrane accretion: Chapter "Low-Grade Metamorphic Conditions and Isotopic Age Constraints of the La Horqueta pre-Carboniferous Sequence, Argentinian San Rafael Block" by H. Tickyj, C. Cingolani, R. Varela and F. Chemale Jr, is dedicated to the siliciclastic sedimentary La Horqueta Formation of Middle Paleozoic age. It is characterized by asymmetric open to similar folds, with southeast vergence that underwent very low-grade (high anchizonal) to low-grade (epizonal) metamorphic conditions that slightly increase from south to north in an intermediate pressure regime. Whole-rock Rb-Sr isochronic ages were obtained on metapelites from the key outcrops indicating that metamorphism and deformation occurred during the Devonian Chanic Orogenic phase, probably related to Chilenia terrane collision (see Fig. 5). U-Pb (LA-MC-ICP-MS) detrital zircon age patterns suggest that the La Horqueta Formation received a dominant sedimentary input from Mesoproterozoic sources. In Chapter "La Horqueta Formation: Geochemistry, Isotopic Data and Provenance Analysis", P. Abre, C. Cingolani, F. Chemale Jr., and N. Uriz expose the provenance analyses based on whole-rock geochemistry and isotope data for the La Horqueta Formation. Whole-rock geochemical data point to a derivation from a source slightly less evolved than the average upper continental crust. The εNd values are within the range of variation of data from the Mesoproterozoic Cerro La Ventana Formation, which is part of the basement of the Cuyania terrane outcropping within the San Rafael Block. Despite geochemical

similarities this unit display different proportions of detrital zircon ages, when compared to the Río Seco de los Castaños Formation. Chapter "Silurian-Devonian Land-Sea Interaction Within the San Rafael Block, Argentina: Provenance of the Río Seco de los Castaños Formation" by C. Cingolani, N. Uriz, P. Abre, M. Manassero, M. A. S. Basei deals with the Río Seco de los Castaños Formation as one of the most relevant 'pre-Carboniferous units' outcropping within the San Rafael Block assigned to Upper Silurian-Lower Devonian age. The authors review the provenance data obtained by petrography and geochemical-isotope analyses as well as the U-Pb detrital zircon ages. Comparison with the La Horqueta Formation is also discussed. These data suggest an Early Carboniferous (Mississipian) low-metamorphic (anchizone) event for the unit correlated with the Chanic tectonic phase that affected the Cuyania terrane and also linked to the collision of the Chilenia terrane in the western pre-Andean Gondwana margin (Fig. 5). The authors comment that the studied Río Seco de los Castaños samples show dominant source derivation from Famatinian (Late Cambrian-Devonian) and Pampean-Brasiliano (Neoproterozoic-Early Cambrian) cycles. Detritus derived from the Mesoproterozoic basement are scarce. U-Pb data constrain the maximum sedimentation age to the Silurian-Early Devonian. In Chapter "Primitive Vascular Plants and Microfossils from the Río Seco de los Castaños Formation, San Rafael Block, Mendoza Province, Argentina", by E. Morel, C. Cingolani, D. Ganuza, N. Uriz and J. Bodnar, the authors describe fossil plant remains that comprise non-forked and forked axes without or with delicate lateral expansions. They refer them to primitive land plants and discuss about their systematic affiliation. Diverse acritarch assemblages are present in the same unit. On the basis of the taxonomical information and stratigraphic correlation, they could infer that the Río Seco de los Castaños Formation has an Early Devonian age. The taphonomical conditions of this fossil association would indicate that the plants were transported some distance from their presumed coastal and riverbank habitats in a warm to cool temperate paleoclimatic conditions. Chapter "The Rodeo de la Bordalesa Tonalite Dykes as a Lower Devonian Magmatic Event: Geochemical and Isotopic Age Constraints" by C. Cingolani, E. Llambías, M. A. S. Basei, N. Uriz, F. Chemale Jr. and P. Abre is dedicated to describe small intrusive bodies in the Río Seco de los Castaños unit composed of tonalite, lamprophyre ('spessartite-kersantite') and aplite dykes. Geochemical and isotopic data from the grey tonalitic rocks were characterized by high to medium potassium concentration, with metaluminous composition and I-type calc-alkaline signature. The 401 ± 4 Ma U-Pb zircon age corresponds to the emplacement time. The Rb-Sr whole-rocks and biotite isochronic age of 374 ± 4 Ma could be related to deformation during the Chanic tectonic phase. The crystallization age corresponds to a Lower Devonian time and suggests that part of the Late Famatinian magmatic event is present in the San Rafael Block. The geochemical and geochronological data allowed us to differentiate the Rodeo de la Bordalesa tonalite from the mafic rocks exposed at the El Nihuil area.

Tectonic evolution synthesis: In Chapter "Pre-Carboniferous Tectonic Evolution of the San Rafel Block, Mendoza Province" by C. Cingolani and V.

A. Ramos, the pre-Carboniferous evolution of the San Rafael Block is described in different stages (Fig. 5). The first one is referred to the Mesoproterozoic basement. The signature of this basement indicates a common origin with the present eastern part of Laurentia. The carbonate platform of Cuyania terrane has been drifted away during Early Cambrian to Early Ordovician times. The Ordovician silico-carbonate sequences of the San Rafael Block are unconformably deposited over the basement near the present eastern slope of the Cuyania terrane. The El Nihuil dolerites with a tholeiitic ocean floor signature considered the southern end of the Famatinian ophiolites were interpreted as a Late Ordovician–Early Silurian extensional event. The collision of Cuyania produced a new west polarity subduction and a magmatic arc, represented by the Devonian Rodeo de la Bordalesa tonalite and some granitoids of the Agua Escondida Mining District. The Late Silurian–Early Devonian sequences of La Horqueta and Río Seco de los Castaños formations were deformed during the collision and accretion of the Chilenia terrane against the proto-Andean margin, and recorded an east vergent cleavage developed on the previous deformed rocks (Fig. 5). This collision produced the strong angular unconformity between the La Horqueta/Río Seco de los Castaños Formations and the El Imperial Formation (Upper Paleozoic). The new subduction with east polarity characterized the beginning of the Gondwanian cycle. The new magmatic arc was interrupted by the intense Lower Permian deformation of the San Rafael tectonic phase (Fig. 5).

Compilation of the San Rafael geological map: to conclude the book, a compilation of the San Rafael Geological Map updated with the new information is offered. It is subdivided into three parts: the northern sector corresponds to Sierra de las Peñas, the central to Sierra Pintada-Cerro Nevado and the southern to La Escondida mining district (34° 14′S to 36° 10′S—68° 06′W to 69° 06′W). Also as supplementary material, we present a complete geological map of the San Rafael Block that will allow readers to obtain more details of the studied pre-Carboniferous units. These compilations were done with the collaboration of Mario Campaña and Norberto Uriz from the Department of Geology of the La Plata Museum.

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