Journal of South American Earth Sciences 111 (2021) 103432

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

The Rinconada phase: A regional tectono-metamorphic event of Silurian age in the pre-Andean basement of Argentina

C. Casquet[a,*], C. Ramacciotti[b], M.A. Larrovere[c,d], S. Verdecchia[b], J. Murra[b], E.G. Baldo[b], R. J. Pankhurst[e], C.W. Rapela[f]

[a] Departamento de Mineralogía y Petrología, Universidad Complutense, 28040, Madrid, Spain
[b] Centro de Investigaciones en Ciencias de La Tierra, Consejo Nacional de Investigaciones Científicas y Técnicas (CICTERRA-CONICET), Universidad Nacional de Córdoba, X5016, Córdoba, Argentina
[c] Centro Regional de Investigaciones Científicas y Transferencia Tecnológica de la Rioja (Prov. deLa Rioja-UNLaR-SEGEMAR-UNCa-CONICET), Entre Rios y Mendoza s/n, 5301, Anillaco, Argentina
[d] Instituto de Geología y Recursos Naturales, Centro de Investigación e Innovación Tecnológica, Universidad Nacional de La Rioja (INGeReN-CENIIT-UNLaR), Avda. Gob. Vernet y Apóstol Felipe, 5300, La Rioja, Argentina
[e] British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK
[f] Centro de Investigaciones Geológicas (CIG), CONICET–UNLP, Calle 1 No. 644, 1900, La Plata, Argentina

ARTICLE INFO

Keywords:
The Rinconada tectonic phase
Famatinian orogeny
Geochronology
Argentina

ABSTRACT

A Silurian regional tectonometamorphic event has been widely recorded by different geochronological methods in the Sierras Pampeanas, NW Argentina and the Precordillera. It took place between ca. 445 and 420 Ma after the regional Hirnantian (late Ordovician) glaciogenic sedimentation. Three domains are recognized. 1) The eastern Sierras Pampeanas and the Puna mainly record focused westward ductile thrusting and heating. 2) In the westernmost Sierras Pampeanas (Maz, Espinal, and Umango) garnet-amphibolite facies metamorphism, penetrative foliation development and westward ductile thrusting (nappes) took place. 3) In the Precordillera, the Rinconada formation of Silurian age consisting of chaotic olistoliths of Ordovician and Cambrian age correlates with this event. The three domains correspond to the hinterland, the internal hot and thickened metamorphic core, and the foreland respectively of an orogenic belt. Remarkably no Cordilleran-type magmatism of this age has been recorded. The regional importance of this event was overlooked so far.

1. Introduction

The Famatinian orogeny involved sedimentation, deformation and magmatism that took place between late Cambrian and Devonian, according to the original definition by Aceñolaza and Toselli (1976). This definition sets arbitrary time-boundaries within what in fact is a continuous accretionary orogeny (*sensu* Cawood et al., 2009) along the continental SW margin of Gondwana that started in the early Paleozoic (proto-Andean margin) and continues today (Andean margin).

In terms of the original definition, the Famatinian orogeny is recognized along the whole South American Andean foreland from Patagonia to the Venezuelan Andes (e.g., Ramos, 2018). However it is particularly well exposed in the Sierras Pampeanas, and in North-West Argentina (NWA), the Puna and the Cordillera Oriental. Here it overprints the older, collisional, Pampean orogeny (545-520 Ma) that brought to an end the amalgamation of Gondwana in the early Cambrian (Casquet et al., 2018 and refs. therein). The Famatinian overprint is recognized across an enormous region some 400 km wide. The belt consists of a lower structural level where low-to high-grade regional metamorphism and plutonism are widespread (the Sierras Pampeanas) and an upper level of weakly or non-metamorphosed sedimentary rocks with volcanics, and shallow plutonic rocks (the NWA and the southern Puna). To the west of the Sierras Pampeanas is the Precordillera, a morphotectonic part of the Andean belt, where an early Cambrian to Devonian sedimentary succession has long been recognized (Astini et al., 1995) Fig. 1.

Several unconformities in the shallow part of the belt attest to tectonic discontinuities in the mainly marine late Cambrian, Ordovician and Silurian sedimentary record. They are from bottom to top the Iruya, Tuambaya, Guandacol and Ocloya unconformities (Moya, 2015 and refs.

* Corresponding author.
E-mail address: casquet@ucm.es (C. Casquet).

https://doi.org/10.1016/j.jsames.2021.103432
Received 2 June 2021; Accepted 13 June 2021
Available online 18 June 2021

therein). The Silurian sedimentary record however is continuous in the most external basin (in the NWA Sierras Subandinas) and discontinuous in the Cordillera Oriental and the Puna. Early Carboniferous continental sediments unconformably overlie the Famatinian belt that was variably exhumed at the time (Moya, 2015).

The unconformities above have a counterpart in the deeper parts of the orogenic belt in the form of peaks of magmatism, deformation and metamorphism recognized through extensive geochronology work. The Iruya angular unconformity is locally preserved. Post-Pampean sedimentary rocks (younger than 520 Ma) underwent folding and foliation before the Cambrian-Ordovician boundary, probably between ca. 490 and 485 Ma (Collo et al., 2011; Rapela et al., 2016; Ramacciotti et al., 2018). Magmatism between 485 and 480 Ma that we correlate with the Tumbaya angular unconformity is represented by poorly preserved Cordilleran-type arc and back-arc extensional magmatism, including hot shallow peraluminous granitoids and bimodal volcanism (basalt-rhyolite) (Suzaño et al., 2017; Rapela et al., 2018; Casquet et al., 2021). A second peak between ca 473 a 468 Ma probably correlated with the Guandacol angular unconformity corresponds to a well preserved second cordilleran-type magmatic arc ranging from gabbro to leucogranite and felsic volcanics and volcanoclastic rocks (Ducea et al., 2017; Rapela et al., 2018). The Ocloya unconformity is not matched in the geochronological record. The Ocloya unconformity is not angular and underlies widespread Hirnantian glaciogenic sediments (Zapla, Mecoyita and Salar del Rincón formations of the Sierras Subandinas, Cordillera Oriental and Puna Occidental respectively), apparently reflecting eustatism and/or uplift between ca. 450 - 445 Ma (Moya, 2015).

2. The Silurian tectonometamorphic event

In recent years geochronological evidence has grown suggesting that a widespread tectonothermal event took place in the Silurian, mainly between ca. 445 and 420 Ma. Table 1 shows a number of cases where ages between approx. 450 and 410 Ma were reported applying different methods. Data are listed by: a) dating systematics and b) location (i.e., the name of the sierra as in Fig. 1), ordered from east to west within each systematic group. These ages were recorded in part from large shear zones, either new or reactivated older shears (Larrovere et al., 2020 and refs. Therein). The shear sense often indicates westward thrusting, i.e., hanging wall to the west, and the temperature attained was moderate to high (500-600 °C). Silurian shears are common in the central and eastern Sierras Pampeanas and the eastern Puna. Moreover, Silurian garnet-amphibolite facies regional metamorphism, with related folding, foliation, granitoids and shear zones bounding thrust nappes, has been recognized in the westernmost Sierras Pampeanas (Maz, Espinal and Umango; Casquet et al., 2005, 2008; Webber, 2018 among other). Remarkably no magmatism of the Cordilleran-type has been described related to this event although metamorphism-related pegmatites and granitoids are common. The list thus embraces a number of processes. The more reliable results emerging from Table 1 are summarised below.

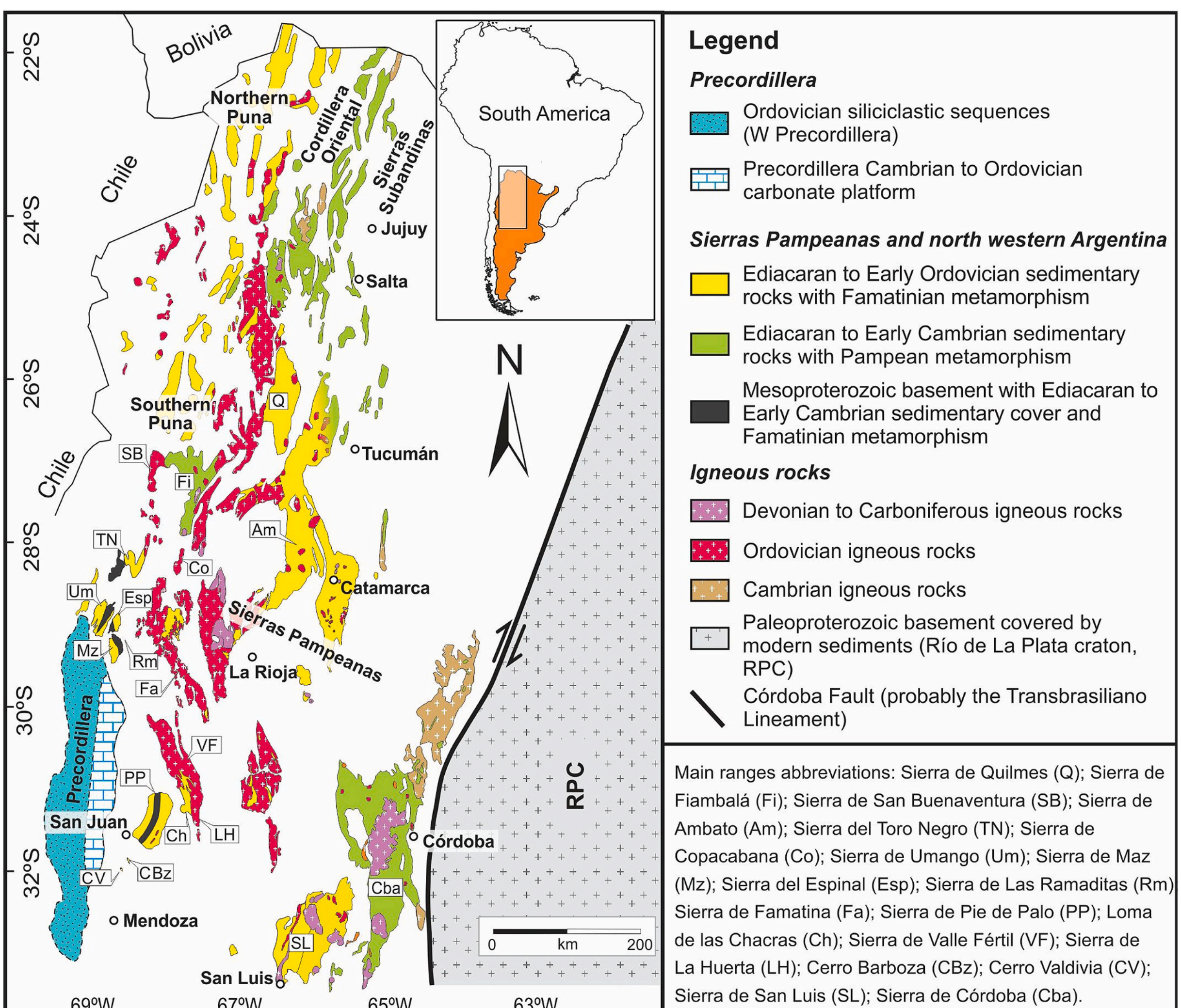

Fig. 1. Schematic map of basement outcrops of W- and NW-Argentina.

Table 1
Recorded radiometric ages related to the Rinconada orogenic phase. 1-Mulcahy et al., 2011. 2-Vujovich et al., 2004. 3-Lucassen and Becchio (2003). 4-Bahlburg et al., 2016. 5-Tholt, 2018. 6-Webber, 2018. 7-Casquet et al., 2008. 8-Larrovere et al., 2020. 9-Finch et al., 2017. 10-Farias et al., 2020. 11-Wolfram et al., 2019. 12-Rapela et al., 1998. 13-Varela et al., 2011. 14-Lucassen et al., 2000. 15-Steenken et al., 2008. 16-Wegmann et al., 2008. 17-Büttner et al., 2005. 18-Collo et al., 2008. 19-López et al., 2000. 20-Steenken et al., 2010. 21-Ramos et al., 1996. 22-Grissom et al., 1998. 23-Mulcahy et al., 2014. 24-Castro de Machuca et al. (2008). 25-Castro de Machuca et al. (2012). 26-González et al., 2004. 27-Whitmeyer, 2008. 28-Simpson et al., 2003.

Location	Rock	Mineral	System	Age	error	Ref.
Sierra de Pie de Palo	Pegmatitic leucogranite	Zircon	U–Pb	439	6	1
–	Orthogneiss	–	–	453	5	1
–	Foliated granodiorite	–	–	454	8	1
–	Granite	–	–	455	10	2
Puna	Impure marble	Titanite	–	444	3	3
–	Impure marble	–	–	451	4	3
–	Granitoid	Zircon	–	443	6	4
–	Granitoid	–	–	444	5	4
–	Granitoid	–	–	444	4	4
–	Granitoid	–	–	444	3	4
–	Granitoid	–	–	447	6	4
Sierra de Ramaditas	Gneiss	Monazite	–	426	7	5
–	Granitic intrusion	Zircon	–	418	4	6
–	Granitic intrusion	–	–	420	5	6
–	Calc-silicate gneiss	–	–	442	3	7
–	Leucosome pegmatite	–	–	445	5	6
–	Tonalite orthogneiss	–	–	447	7	6
Sierra de Ambato	Schist	Monazite	–	440	6	8
Sierra de Maz	Schist	–	–	411	2	5
–	Metapelite	–	–	413	5	5
–	Schist	–	–	419	3	5
–	Tonalite orthogneiss	Titanite	–	419	20	6
–	Calc-silicate	–	–	428	6	3
–	Metagreywacke	–	–	438	7	6
–	Calc-silicate	–	–	443	3	3
–	Granitic intrusion	Zircon	–	410	10	6
–	Leucosome mylonite	–	–	422	9	6
–	Leucosome pegmatite	–	–	425	9	6
–	Leucosome pegmatite	–	–	435	7	6
–	Leucosome pegmatite	–	–	447	3	6
Sierra de Quilmes	Schist	Monazite	–	421	2	9
–	Schist	–	–	435	2	9
–	Calc-silicate	Titanite	–	418	11	10
–	Calc-silicate	–	–	428	11	10
–	Calc-silicate	–	–	436	5	10
–	Calc-silicate	–	–	442	8	10
–	Anatectic granite	Zircon	–	447	4	11
Sierras de Córdoba	Trondhjemite	Monazite	–	438	9	12
Sierra de Toro Negro	Calc-silicate	Titanite	–	432	3	3
Sierra de Umango	Mylonite	Monazite	–	452	12	13
–	Marble	Titanite	–	422	5	3
–	Marble	–	–	425	4	3
–	Amphibolite	Zircon	–	428	12	13
–	Amphibolite	–	–	446	3	13
Sierra de Quilmes	Mylonitic gneiss	WR-Min isochron	Sm–Nd	412	18	14
–	Mylonitic gneiss	–	–	442	9	14
Sierra de San Luis	Meta-ultramafic rock	–	–	434	12	15
Cordillera Oriental	Granitoid mylonite	Muscovite – K-feldspar	Rb–Sr	428	5	16
–	Granitoid mylonite	–	–	437	4	16
Sierra de Quilmes	Pegmatite	Muscovite –Plagioclase	–	438	5	17
–	Pegmatite	–	–	440	5	17
–	Pegmatite	–	–	441	5	17
Sierra de San Luis	Migmatite	Biotite	–	422	9	15
–	Schist	Muscovite	–	439	9	15
Sierra de Ramaditas	Gneiss	WR – Garnet	Lu–Hf	449	2	5
Sierra de Maz	Metapelite	–	–	423	10	5
–	Mafic orthogneiss	–	–	428	9	5
–	Schist	–	–	429	5	5
Sierra de Famatina	Pelite	Illite	K–Ar	435	12	18
–	Phyllonite	Whole rock	–	444	8	18
Puna	Amphibolite	Amphibole	–	411	9	14
–	Amphibolite	–	–	446	11	14
–	Gneiss	Biotite	–	420	9	14
–	Gneiss	–	–	426	9	14
Sierra de Copacabana,	Granitoid mylonite	Muscovite	–	436	10	19
Sierra de Quilmes	Pegmatite	–	–	420	12	17
–	Pegmatite	–	–	435	10	17
Sierra de San Luis	Amphibolite	Amphibole	–	411	10	15
–	Leucomonzogranite	Biotite	–	411	9	15
–	Mylonite	–	–	414	10	15

(continued on next page)

Table 1 (*continued*)

Location	Rock	Mineral	System	Age	error	Ref.
–	Migmatite	–	–	418	10	15
–	Schist	–	–	437	8	15
–	Pegmatite	Muscovite	–	408	8	15
–	Pegmatite	–	–	408	9	15
–	Migmatite	–	–	412	7	15
–	Pegmatite	–	–	417	9	15
–	Gneiss	–	–	420	10	15
–	Leucogranite	–	–	420	9	15
–	Schist	–	–	432	6	15
–	Pegmatite	–	–	438	10	15
–	Pegmatite	–	–	438	9	15
–	Granite	–	–	439	10	15
–	Pegmatite	–	–	440	9	15
–	Gneiss	–	–	440	9	15
–	Pegmatite	–	–	442	9	15
–	Pegmatite	–	–	447	9	15
–	Pegmatite	–	–	448	11	15
Sierras de Córdoba	Amphibolite	Amphibole	–	434	5	20
–	Amphibolite	–	–	434	5	20
–	Amphibolite	–	–	447	11	20
–	Amphibolite	–	–	447	11	20
–	Migmatite	Biotite	–	423	9	20
–	Diatexite	–	–	423	6	20
–	Metagabbro	–	–	426	8	20
–	Mylonite	–	–	430	5	20
–	Gneiss	–	–	433	4	20
–	Phyllite	Illite	–	420	7	20
–	Phyllite	–	–	440	6	20
–	Pegmatite	Muscovite	–	406	12	20
–	Pegmatite	–	–	413	9	20
–	Pegmatite	–	–	414	4	20
–	Pegmatite	–	–	416	5	20
–	Pegmatite	–	–	417	7	20
–	Pegmatite	–	–	418	5	20
–	Pegmatite	–	–	419	10	20
–	Migmatite	–	–	424	6	20
–	Pegmatite	–	–	425	5	20
–	Mylonite	–	–	427	5	20
–	Pegmatite	–	–	427	6	20
–	Mylonite	–	–	428	5	20
–	Mylonite	–	–	430	5	20
–	Gneiss	–	–	431	5	20
–	Mylonite	–	–	431	7	20
–	Pegmatite	–	–	431	7	20
–	Gneiss	–	–	432	5	20
–	Pegmatite	–	–	432	5	20
–	Pegmatite	–	–	434	5	20
–	Pegmatite	–	–	436	5	20
–	Migmatite	–	–	438	7	20
–	Pegmatite	–	–	440	5	20
–	Pegmatite	–	–	441	5	20
–	Mylonite migmatite	–	–	435	7	20
–	Mylonite migmatite	–	–	442	7	12
–	Mylonite migmatite	–	–	447	7	12
–	Calc-silicate	Phlogopite	–	420	10	20
Cerro Barboza	Amphibolite	Amphibole	$^{40}Ar/^{39}Ar$	425	0.3	21
Cerro Valdivia	Pegmatoid	Muscovite	–	425	0.2	21
Sierra de Fiambalá	Calc-silicate	Amphibole	–	443	1	22
Loma Las Chacras	Amphibolite	–	–	439	10	23
–	Amphibolite	Biotite	–	432	8	23
–	Amphibolite	–	–	444	6	23
–	Amphibolite	–	–	445	7	23
Sierra de Pie de Palo	Leucogranite	Muscovite	–	413	0.3	21
–	Schist	–	–	417	2	1
–	Schist	–	–	432	0.2	21
–	Metavolcanic	–	–	436	4	1
–	Schist	–	–	439	7	1
Sierra de La Huerta	Metagabbro mylonite	Amphibole	–	432	4	24
–	Metagabbro mylonite	–	–	439	2	25
–	Metagabbro mylonite	–	–	442	2	25
Sierra de San Luis	Amphibolite	–	–	416	2	15
–	Amphibolite	–	–	445	2	26
Sierras de Córdoba	Pseudotachylite	–	–	429	4	27
–	Pseudotachylite	Biotite	–	428	12	28

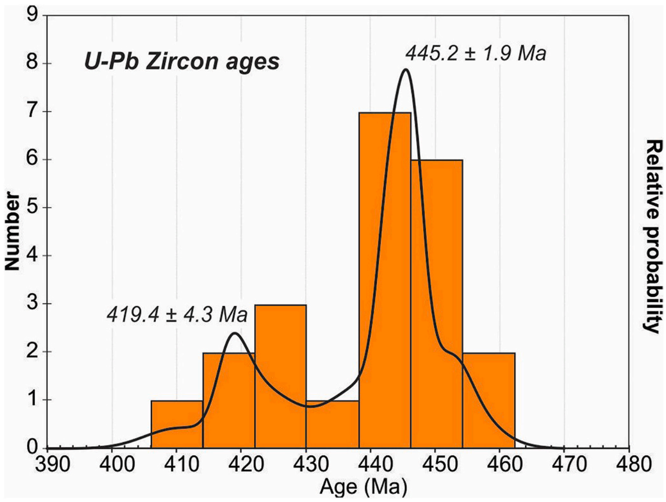

Fig. 2. Probability density plot of U–Pb zircon ages.

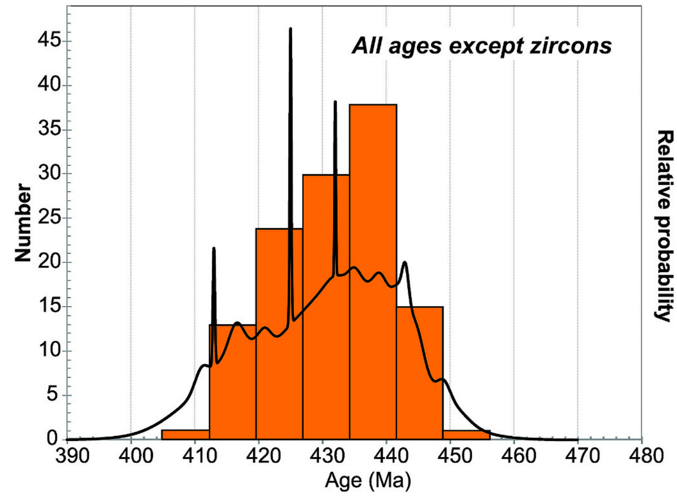

Fig. 3. Probability density plot of all ages less zircon.

U–Pb zircon ages (n = 22) range from ca. 410 to 455 Ma; sixteen are between ca. 430 and 450 Ma and yield a weighted mean of 445 ± 2 Ma (MSWD = 2.7). Apparently there is a minor peak at 419 ± 4 Ma (n = 6; MSWD = 1.6) (Fig. 2). U–Pb titanite ages (n = 13) range almost continuously from ca. 418 to 451 Ma and yield a young and less precise mean than zircon (437 ± 6 Ma; MSWD = 17). Monazite ages (n = 9) range between 411 ± 2 and 452 ± 12 Ma. Age dispersion increases in the group of ages obtained by $^{40}Ar/^{39}Ar$ and K–Ar methods. Thus amphibole $^{40}Ar/^{39}Ar$ ages (n = 8) yield a mean of 430 ± 4 Ma (but with MSWD = 88). Muscovite ages (n = 46) yield an almost continuous range of values between 448 ± 11 and 406 ± 12 Ma. Rb–Sr and Sm–Nd isochron ages from metamorphic pegmatites and sheared rocks are ca. 440 Ma in most cases, i.e., close to the U–Pb mean age. All compiled ages excluding zircon ages are grouped in Fig. 3. A wide peak around 440 Ma is recognized that encompasses the peak of zircon ages.

3. Discussion

All the structural evidence gathered so far suggests that the Silurian tectonothermal event was mainly contractional and west-directed. Deformation was focused along discrete hot shear zones in the east (e.g., Larrovere et al., 2020) and was more penetrative, with regional metamorphism up to upper amphibolite facies in the west.

The geochronological evidence suggests that the main shearing and the peak of metamorphism took place at 445 ± 2 Ma (U–Pb zircon weighted mean age), and that the bulk of mineral ages resulted from a combination of heating/cooling and protracted episodic shearing with mineral deformation and recrystallization. Cooling rates within the shear zones and in the metamorphic areas were very variable from one place to another as evidenced by $^{40}Ar/^{39}Ar$ and K–Ar muscovite ages that reflect Ar-diffusion closure temperature ages. This variability suggests that heating and cooling were largely restricted to within the shear zones. Cooling locally persisted down to ca. 410 Ma, i.e., the youngest $^{40}Ar/^{39}Ar$ and K–Ar mica ages.

The older zircon ages (including the geological uncertainties) suggest that the tectonometamorphic event began shortly after the Hirnantian (445.2 ± 1.4 to 443.8 ± 1.5 Ma; chronostratigraphy corresponds to the updated version (2021) International Chronostratigraphic Chart (Cohen, et al., 2013)), when glaciogenic sedimentation took place across the whole Famatinian realm including the Precordillera (Don Braulio Formation). Notably, the Ocloya unconformity beneath the Hirnantian sedimentary rocks did not result from orogeny (Moya, 2015). Silurian sedimentation in the Cordillera Oriental and Sierras Subandinas apparently was continuous (Moya, 2015). Silurian sedimentary rocks are scarce or absent in the western Puna and in the Sierra de Famatina. However the Villacorta Formation in the latter, which discordantly overlies the early Ordovician Suri Formation, has been dated as late Silurian (Wenlock-Ludlow; ca. 433-423 Ma) by palynology (Marenssi et al., 2020). It is a shallow, marine and continental formation, which suggests that the Sierra de Famatina sector was probably exposed to erosion at that time. In consequence the Silurian tectonometamorphic contractional event dealt with here had to have taken place mainly between the widespread Hirnantian glaciogenic sedimentation and the Wenlock-Ludlow (middle-late Silurian) uplift.

Remarkably, deformation in the eastern Precordillera to the west of the Sierras Pampeanas occurred after the Hirnantian glaciogenic sedimentation (Don Braulio Formation). In fact the Rinconada Formation, which overlies the Don Braulio Formation, is a chaotic formation that includes large blocks (olistoliths) of the Cambrian to early Ordovician carbonate platform and of the eastern crystalline basement itself. This formation was long assigned a Silurian age (Astini et al., 1995; Keller and Lehnert, 1998). More recently Voldman et al. (2018) show that the top of the formation has a late Wenlock-early Ludlow maximum age based on graptolites and conodonts. The maximum age of the base of the formation is defined by the Hirnantian Don Braulio Formation. Voldman et al. (2018) proposed a model to explain this chaotic syn-orogenic deposit. The latter formation would have been deposited in front (foreland) of an orogenic wedge of pre-Silurian basement that was thrust westwards during a contractional tectonic phase. Voldman et al. (2018) loosely correlate this tectonic event with Silurian ductile shearing in the nearby Sierras Pampeanas dated at ca. 442-439 Ma by Castro de Machuca et al. (2012).

In consequence we argue that the Silurian tectonometamorphic event recognized in the Sierras Pampeanas and in the NWA does not correspond to the pre-Hirnantian Ocloya unconformity. Moreover the event was a contractional tectonic phase whose regional importance was overlooked so far. Whereas the Hirnantian was a time of regional stability, the Silurian tectonometamorphic event was a discrete period of widespread deformation in the Famatinian realm that was accompanied by regional heating up to amphibolite facies conditions and penetrative deformation in the west, and shearing with focused heating in the east. The eastern domain was thus an orogenic hinterland; the western was a thick and hot metamorphic orogenic core, and the Precordillera was the orogenic foreland. We propose to call this Silurian event the Rinconada phase of the Famatinian orogeny.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Funding was provided by Argentine public grants PUE 2016-CONICET-CICTERRA, CONICET PIP 11220150100901CO, FONCYT PICT 2017–0619 and SECyT 2018–2020, and CGL 2016-76439-P of MINECO (Spain). We acknowledge editorial handling by Dr. Andres Folguera.

References

Aceñolaza, F.G., Toselli, A.J., 1976. Consideraciones estratigraficas y tectonicas sobre el Paleozoico inferior del Noroeste Argentino. Congr. Latinoamericano Geol. Caracas, Actas 2, 755–764.

Astini, R.A., Benedetto, J.L., Vaccari, E.N., 1995. The early Paleozoic evolution of the Argentine Precordillera as a Laurentian rifted, drifted and collided terrane: a Geodynamic model. Geol. Soc. Am. Bull. 107, 253–273.

Bahlburg, H., Berndt, J., Gerdes, A., 2016. The ages and tectonic setting of the Faja Eruptiva de la Puna oriental, Ordovician, NW Argentina. Lithos 256–25, 41–54. https://doi.org/10.1016/j.lithos.2016.03.018. ISSN 0024-4937.

Büttner, S.H., Glodny, J., Lucassen, F., Wemmer, K., Erdmann, S., Handler, R., Franz, G., 2005. Ordovician metamorphism and plutonism in the Sierra de Quilmes metamorphic complex: implications for the tectonic setting of the northern Sierras Pampeanas (NW Argentina). Lithos 83, 143–181.

Casquet, C., Rapela, C.W., Pankhurst, R.J., Galindo, C., Dahlquist, J., Baldo, E.G., Saavedra, J., Gonzalez Casado, J.M., Fanning, C.M., 2005. Grenvillian massif-type anorthosites in the sierras Pampeanas. J. Geol. Soc. 162, 9–12. London.

Casquet, C., Pankhurst, R.J., Rapela, C., Galindo, C., Fanning, C.M., Chiaradia, M., Baldo, E., González-Casado, J.M., Dahlquist, J.A., 2008. The maz terrane: a mesoproterozoic domain in the western sierras Pampeanas (Argentina) equivalent to the arequipa–antofalla block of southern Peru? Implications for western Gondwana margin evolution. Gondwana Res. 13, 163–175.

Casquet, C., Dahlquist, J.A., Verdecchia, S.O., Baldo, E.G., Galindo, C., Rapela, C.W., Pankhurst, R.J., Morales, M.M., Murra, J.A., Fanning, C.M., 2018. Review of the Cambrian Pampean orogeny of Argentina; a displaced orogen formerly attached to the Saldania Belt of South Africa? Earth Sci. Rev. 177, 209–225.

Casquet, C., Alasino, P., Galindo, C., Pankhurst, R.J., Dahlquist, J.A., Baldo, E.G., Ramacciotti, C.D., Verdecchia, S.O., Larrovere, M., Rapela, C.W., Recio, C., 2021. The Faja Eruptiva of the eastern Puna and the sierra de Calalaste, NW Argentina: U–Pb zircon chronology of the early famatinan orogeny. J. Iber. Geol. https://doi.org/10.1007/s41513-020-00150-z.

Castro de Machuca, B., Arancibia, G., Morata, D., Belmar, M., Previley, L., Pontoriero, S., 2008. P-T-t evolution of an Early Silurian medium-grade shear zone on the west side of the Famatinian magmatic arc, Argentina: implications for the assembly of the Western Gondwana margin. Gondwana Res. 13, 216–226.

Castro de Machuca, B., Delpino, S., Previley, L., Mogessie, A., Bjerg, E., 2012. Tectono-metamorphic evolution of a high- to medium-grade ductile deformed metagabbro/ metadiorite from the arenosa Creek shear zone, western sierras Pampeanas, Argentina. J. Struct. Geol. 42, 261–278.

Cawood, P.A., Kröner, A., Collins, W.J., Kusky, T.M., Mooney, W.D., Windley, B.F., 2009. Accretionary Orogens through Earth History, vol. 318. Geological Society of London, Special Publications, pp. 1–36. https://doi.org/10.1144/SP318.1.

Collo, G., Do Campo, M., Niento, F., 2011. Low-grade metamorphism of Cambro-Ordoviciansuccessions in the Famatina belt, Southern-Central Andeas: burial-inversion history linked to the evolution of the proto-Andean Gondwana margin. Andean Geol. 38, 284–318.

Cohen,, K.M., Finney, S.C., Gibbard, P.L., Fan, J.X., 2013. The ICS, International Chronostrtigrphic Chart (2021). Episodes 36, 199–204.

Collo, G., Astini, R.A., Cardona, A., Do Campo, M.D., Cordani, U., 2008. Edad del metamorfismo de las unidades con bajo grado de la región central del Famatina: La impronta del ciclo orogénico oclóyico. Rev. Geol. Chile 35 (2), 191–213.

Ducea, M.N., Bergantz, G.W., Crowley, J.L., Otamendi, J., 2017. Ultrafast magmatic buildup and diversification to produce continental crust during subduction. Geology. https://doi.org/10.1130/G38726.1.

Farias, P., Weinberg, R., Sola, A., Becchio, R., 2020. From cristal thickening to orogen-parallel escape: the 120-Myr-long HT-LP evolution recorded by titanite in the Paleozoic Famatinian backarc, NW Argentina. Tectonics 39, e2020TC006184. https://doi.org/10.1029/2020TC006184.

Finch, M.A., Weinberg, R.F., Hasalová, P., Becchio, R., Fuentes, M.G., Kennedy, A., 2017. Tectono-metamorphic evolution of a convergent back-arc: the Famatinian orogen, Sierra de Quilmes, Sierras Pampeanas, NW Argentina. Bull. Geol. Soc. Am. 129, 1602–1621.

González, P.D., Sato, A.M., Llambías, E.J., Basei, M.A.S., Vlach, S.R.F., 2004. Early paleozoic structural and metamorphic evolution of western sierra de San Luis (Argentina), in relation to Cuyania accretion. Gondwana Res. 7, 1157–1170.

Grissom, G.C., Debari, S.M., Snee, L.W., 1998. Geology of the sierra de Fiambalá, northwestern Argentina: implications for early palaeozoic andean tectonics. In: Pankhurst, R.J., Rapela, C.W. (Eds.), The Proto-Andean Margin of Gondwana, vol. 142. Geological Society of London, Special Publications, pp. 297–323. https://doi.org/10.1144/GSL.SP.1998.142.01.15.

Keller, M., Lehnert, O., 1998. The Rio Sassito pelagic carbonate platform: a pinpoint in the geodynamic evolution of the Argentine Precordillera. Geol. Rundsch. 87, 326–344.

Larrovere, M.A., de los Hoyos, C.R., Willner, A.P., Verdecchia, S.O., Baldo, E.G., Casquet, C., Basei, M.A.S., Hollanda, M.H., Rocher, S., Alasino, P.H., Moreno, G.G., 2020. Mid-crustal deformation in a continental margin orogen: structural evolution and timing of the Famatinian Orogeny, NW Argentina. J. Geol. Soc. 177 (2), 233–257. ISSN 0016-7649, ESSN: 2041-479X.

López, J.P., Sales de López, A., Basei, M.A.S., 2000. Nueva edad K/Ar en la historia deformativa de la Faja Milonítica Tipa, en el Noroeste Argentino. Zentralblatt für Geol. Paläontol. 1, 895–902.

Lucassen, F., Becchio, R., 2003. Timing of high-grade metamorphism: early Palaeozoic U–Pb formation ages of titanite indicate long-standing high-T conditions at the western margin of Gondwana (Argentina, 26–29°S). J. Metamorph. Geol. 21, 649–662. https://doi.org/10.1046/j.1525-1314.2003.00471.x.

Lucassen, F., Becchio, R., Wilke, H.G., Franz, G., Thirlwall, M.F., Viramonte, J., Wemmer, K., 2000. Proterozoic–Paleozoic development of the basement of the Central Andes (18–26°S) – a mobile belt of the South American craton. J. S. Am. Earth Sci. 13, 697–715. https://doi.org/10.1016/S0895-9811(00)00057-2.

Marenssi, S.A., Limarino, C.O., Ferreira, L.C., Ciccioli, P.L., Scarlatta, L.R., Cesari, S.N., Bello, F.C., 2020. La formación Villacorta (nov. nom.): una nueva unidad del Silúrico superior del Sistema del Famatina. Rev. Asoc. Geol. Argent. 77 (4), 591–601.

Moya, M.C., 2015. La "Fase Oclóyica" (Ordovícico Superior) en el noroeste argentino. Interpretación histórica y evidencias en contrario. Ser. Correlación Geol. 31 (1), 73–110.

Mulcahy, S.R., Roeske, S.M., McClelland, W.C., Jourdan, F., Iriondo, A., Renne, P.R., Vervoort, J.D., Vujovich, G.I., 2011. Structural evolution of a composite middle to lower crustal section: the Sierra de Pie de Palo, northwest Argentina. Tectonics 30. https://doi.org/10.1029/2009TC002656.

Mulcahy, S.R., Roeske, S.M., McClelland, W.C., Ellis, J.R., Jourdan, F., Renne, P.R., Vervoort, J.D., Vujovich, G.I., 2014. Multiple migmatite events and cooling from granulite facies metamorphism within the Famatina arc margin of northwest Argentina. Tectonics 33, 1–25. https://doi.org/10.1002/2013TC003398.

Ramacciotti, C.D., Casquet, C., Baldo, E.G., Galindo, C., Pankhurst, R.J., Verdecchia, S. O., Rapela, C.W., Fanning, C.M., 2018. A Cambrian mixed carbonate–siliciclastic platform in SW Gondwana: evidence from the Western Sierras Pampeanas (Argentina) and implications for the early Paleozoic paleogeography of the proto-Andean margin. Int. J. Earth Sci. 107 (7), 2605–2625.

Ramos, V.A., 2018. The Famatinian orogen along the protomargin of Western Gondwana: evidence for a nearly continuous Ordovician magmatic arc between Venezuela and Argentina. In: Folguera, A., Contreras Reyes, E., Heredia, N., Encinas, A., Iannelli, S.B., Oliveros, V., D_avila, F.M., Collo, G., Giambiagi, L., Maksymowicz, A., Iglesia Llanos, M.P., Turienzo, M., Naipauer, M., Orts, D., Litvak, V.D., Alvarez, O., Arriagada, C. (Eds.), The Evolution of the Chilean-Argentinean Andes. Springer International Publishing AG, Cham, pp. 133–161.

Ramos, V.A., Vujovich, G.I., Dallmeyer, D., 1996. Los klippes y ventanas tectónicas de la estructura preándica de la sierra de Pie de Palo (San Juan): edad e implicancias tectónicas. In: 13° Congreso Geológico Argentino and 3° Congreso de Exploración de Hidrocarburos, Actas, vol. 5, pp. 377–391.

Rapela, C.W., Pankhurst, R.J., Casquet, C., Baldo, E., Saavedra, J., Galindo, C., Fanning, C.M., 1998. The Pampean orogeny of the southern proto-Andes: evidence for Cambrian continental collision in the Sierras de Cordoba. In: Pankhurst, R.J., Rapela, C.W. (Eds.), The Proto-Andean Margin of Gondwana, vol. 142. Geological Society of London, Special Publication, pp. 181–217.

Rapela, C.W., Verdecchia, S.O., Casquet, C., Pankhurst, R.J., Baldo, E.G., Galindo, C., Murra, J.A., Dahlquist, J.A., Fanning, C.M., 2016. Identifying Laurentian and SW Gondwana sources in the neoproterozoic to early paleozoic metasedimentary rocks of the sierras Pampeanas: paleogeographic and tectonic implications. Gondwana Res. 32, 193–201.

Rapela, C.W., Pankhurst, R.J., Casquet, C., Dahlquist, J.A., Fanning, M.C., Baldo, E.G., Galindo, C., Alasino, P.H., Ramacciotti, C.D., Verdecchia, S.O., Murra, J.A., Basei, M. A.S., 2018. A review of the Famatinian Ordovician magmatism in southern South America: evidence of lithosphere reworking and continental subduction in the early proto-Andean margin of Gondwana. Earth Sci. Rev. 187, 259–285.

Simpson, C., Law, R.D., Gromet, L.P., Miró, R., Nothrup, C.J., 2003. Paleozoic deformation in the Sierras de Córdoba and Sierra de las Minas, Eastern Sierras Pampeanas, Argentina. J. S. Am. Earth Sci. 15, 749–764.

Steenken, A., Siegesmund, S., Wemmer, K., López de Luchi, M.G., 2008. Time constraints on the famatinian and achalian structural evolution of the basement of the sierra de San Luis (eastern sierras Pampeanas, Argentina). J. S. Am. Earth Sci. 25 (3), 336–358.

Steenken, A., Wemmer, K., Martino, R.D., López de Luchi, M.G., Guereschi, A., Siegesmund, S., 2010. Post-pampean cooling and the uplift of the sierras Pampeanas in the west of Córdoba (central Argentina). N Jb Geol Palaönt Abh 256, 235–255.

Suzaño, N.O., Sola, A.M., Elortegui Palacios, J., Becchio, R.A., Ortiz, A., Nieves, A.A., Quiroga, M.F., 2017. Magmatismo plutónico del Paleozoico inferior de Salta y Jujuy. In: Muruaga, C.M., Grosse, P. (Eds.), Ciencias de la Tierra y Recursos Naturales del NOA. San Miguel de Tucumán: Relatorio del XX Congreso Geológico Argentino, pp. 323–351, 978-987-42-6666-8 323.

Tholt, A., 2018. Master of Science thesis. Metamorphic Evolution of the Sierra de Maz: Implications for the Timing of Terrane Accretion on the Western Margin of Gondwana, vol. 713. WWU Graduate School Collection. https://cedar.wwu.edu/wwuet/713.

Varela, R., Basei, M.A.S., Gonzalez, P.D., Sato, A.M., Naipauer, M., Campos Neto, M., Cingolani, C.A., Meira, V.T., 2011. Accretion of Grenvillian terranes to the southwestern border of the Rio de la Plata craton, western Argentina. Int. J. Earth Sci. 100, 243–272.

Voldman, G., Alonso, J., Fernández, L., Ortega, G., Albanesi, G., Banchig, A., Cardó, R., 2018. Tips on the SW-Gondwana margin: Ordovician conodont-graptolite

biostratigraphy of allochthonous blocks in the Rinconada mélange, Argentine Precordillera. Andean Geol. 45 (3), 399–409. https://doi.org/10.5027/andgeoV45n3-3095.
Vujovich, G.I., van Staal, C.R., Davis, W., 2004. Age constraints on the tectonic evolution and provenance of the pie de Palo complex, Cuyania composite terrane, and the famatinian orogeny in the sierra de Pie de Palo, San Juan, Argentina. Gondwana Res. 7, 1041–1056. https://doi.org/10.1016/S1342-937X(05)71083-2.
Webber, P.M., 2018. Terrane Accretion and Translation on the Western Margin of Gondwana. Master of Science thesis. University of Iowa. https://doi.org/10.17077/etd.0ymp2eyn.
Wegmann, M.I., Riller, U., Hongn, F.D., Glodny, J., Oncken, O., 2008. Age and kinematics of ductile deformation in the Cerro Durazno area, NW Argentina: significance for orogenic processes operating at the western margin of Gondwana during Ordovician–Silurian times. J. S. Am. Earth Sci. 26, 78–90. https://doi.org/10.1016/j.jsames.2007.12.004.
Whitmeyer, S., 2008. Dating fault fabrics using modern techniques of 40Ar/39Ar thermochronology: evidence for Paleozoic deformation in the Eastern Sierras Pampeanas, Argentina. In: Declan De Paor, Making Sense of Shear (In Honour of Carol Simpson), vol. 30. Journal of the Virtual Explorer, p. 3. https://doi.org/10.3809/jvirtex.2008.00207.
Wolfram, L.C., Weinberg, R.F., Nebel, O., Hamza, K., Hasalová, P., Míková, J., Becchio, R., 2019. A 60-Myr record of continental back-arc differentiation through cyclic melting. Nat. Geosci. 12 (3), 215–219. https://doi.org/10.1038/s41561-019-0298-6.